

SCHOOL OF  
CIVIL ENGINEERING  
INDIANA  
DEPARTMENT OF HIGHWAYS

JOINT HIGHWAY RESEARCH PROJECT

JHRP-87/12

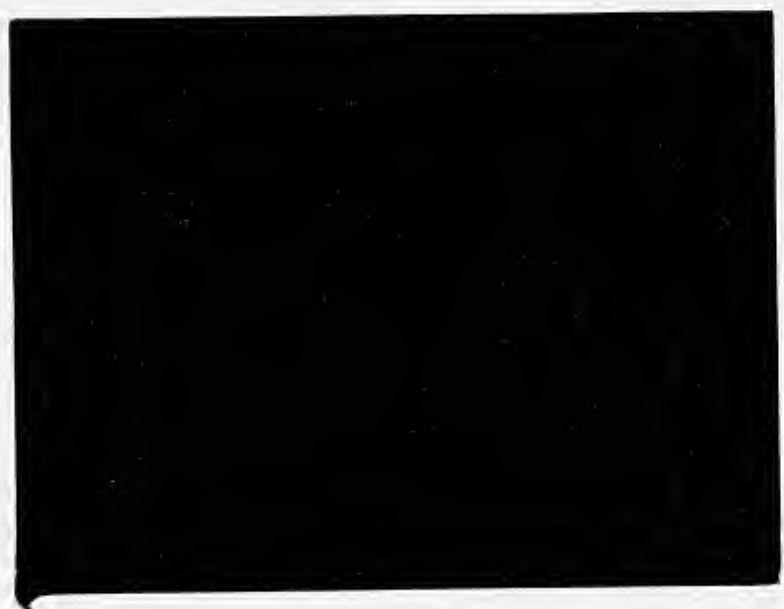
Informational Report

PLACEMENT RATES FOR HIGHWAY  
EMBANKMENTS WITH VERTICAL AND  
HORIZONTAL DRAINAGE

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PURDUE UNIVERSITY



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Informational  
Report on  
Placement Rates for Highway Embankments  
with Vertical and Horizontal Drainage

Prepared for  
State of Indiana, Department of Highways

By  
A. G. Altschaeffl  
S. Thevanayagam

March 1987



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## 1. Introduction

"Modified Sand" is a computer program for the general analysis of an embankment foundation on a soft soil with consideration of vertical and horizontal consolidation without any sand drain installations. This is a modified version of the program SAND (Krizek and Krugmann, 1972) that can be used to analyze this problem with consideration of vertical sand drains. The solution technique in the modified program remains the same as in the original program.

### 1.1 Capabilities of Modified Sand

This program optimizes the rate at which a specific highway embankment can be constructed on soft soil. This problem involves the computation of stresses and pore pressures in the subsoil, the dissipation of these pore pressures, the corresponding increase in shear resistance and stability of the embankment.

The embankment load which is assumed to act vertically, induces pore pressures in the subsoil which are computed using Theory of Elasticity and Skempton's pore pressure parameters (A, B). These pore pressures dissipate according to three dimensional consolidation theory which takes into account the effect of gas and variable soil parameters. The solution of consolidation equations are solved numerically by treating it as an eigenvalue problem. As the pore water pressure dissipates the effective stresses in the subsoil will increase giving a simultaneous



increase in shearing resistance. Settlements are computed from the dissipated pore pressures.

There are two options available.

Option 1: (For  $ISP = 0$ ) -- The program determines the times at which each lift whose resulting shapes are input can be constructed without exceeding the bearing capacity of the subsoil and after a specified fraction of a reference settlement has occurred. Settlements and average degree of consolidation are output for specified points in a graphical form.

Option 2: ( $ISP = 1$ ) -- The lifts and times of lift application are input and the program determines the dissipation of pore pressures and settlements for specified points. Bearing capacity of the foundation soil is not analyzed.

## 2. Description of the Program

Described in the subsequent sections is the set of computer programs which can be used to analyze an embankment foundation on a soft soil with consideration of vertical and horizontal consolidation. Individual routines, consisting of main program "Modified Sand" are written in FORTRAN 77. Program listing is attached in Appendix A. The programs have been tested in IBM PC XT and VAX 11/780 at Purdue University.

Each subsection of the program is given below explaining the following:

1. Purpose of the program.
2. Usage of the program.
3. Block names.
4. Description of parameters.
5. Method of solution or calculation.
6. Subroutines required.

In addition a list of sequence of input of data into the main program is given.

Two sample problems which illustrate most of the special features of the programs and solutions to these problems are attached.

## 2.1 The Main Program Modified SAND

### Purpose of the Programs:

SAND -- To analyze an embankment foundation on a soft soil for stability and/or settlements and consolidation behavior with consideration of horizontal and vertical drainage.

### Block Names and Lengths:

SAPOD/	IOUTP,W,HH,GLOAD,CLOAD,NARC,NRAD;	length: 7 words	
SADI1/	LAYER,IBCV,MHE,M,N,IDC,NDR,ISUM; XET(41);	length: 49 words	
SADI2/	FIMPV,RC,RK,C,RO,RE,TA,ISP,IVAR;	length: 29 words	
SACSE/	ROC,ROCL,SVM,P,PC,PLOG,PO,PCO,IAV,IK,ISAT,AAV,AAH;	length: 54 words	

SAC01/ AVOC,KVO,KHO,EOPUS,PU,SKHM,SKVM,CCC,NNN,ICOEF; length: 10 words  
SAC02/ PCV(10),CVIN(10),PCH(10),CHIN(10),ICV,KOUNT,HF; length: 43 words  
SADET/ XSTAB(51),YSTAB(11),DX,DY,YWM,TGPFI; length: 66 words

These blocks are only defined in program SAND

SAPOD is needed in subroutines DETFS,DISP,INIT,PORE, and VARYR  
SADI1 and SADI2 are needed in subroutine DISP  
SACSE is needed in subroutines COEF and SETL  
SAC01 and SAC02 are needed in subroutine COEF  
SADET is needed in subroutine DETFS

### Description of Parameters

On the following pages are described the parameters which are input by the user; quantities listed in labelled COMMON blocks are given in the respective subroutines. This list is given in alphabetical order. Section (3) provides the list where data cards of the parameters appear in the sequence in which they are needed in the programs. The asterisk \* refers to a note at the end of the list.

- A - Skempton's pore pressure coefficient
- AVO - constant coefficient of compressibility to be used in the settlement computations; in the case of two layers, AVO applies to the upper layer; dimension; ft/lb
- AX(I) - subinterval limits to be input as decimal fractions of reference value W; I=1,NI where NI < 5

- B           - Skempton's pore pressure coefficient
- BLANK       - symbol to be used in the resulting plots
- C           - fraction of the reference load at time TA, which  
              is applied at time equal to zero; may vary  
              between 0.0 and 1.0
- CC          - compression index; negative slope of the void  
              ratio versus effective stress curve (virgin  
              part of the curve); in the case of two layers,  
              CC is the compression index of the upper layer
- CLOAD       - undrained strength of the embankment oil  
              dimension - psf
- CO(I)       - initial undrained strength of the subsoil; I=1,  
              NC where  $NC \leq MYE \leq 11$ . If  $NC < MYE$ ,  
              Lagrangean interpolation is used to compute  
              the undrained strengths at MYE equally spaced  
              depths. If  $NC=MYE$ , the input values must be  
              provided at equally spaced points where I=1 and  
              I=MYE coincide with the surface and the  
              bottom of the compressible layer, respectively;  
              dimension - psf
- COUNT\*      - marker to indicate the last residual pore water  
              pressure data card; this parameter is zero  
              on all residual pore water pressure data  
              cards, except on the last card, where it  
              must take value different from zero
- CP(I)       -  $(c/\bar{p})$ -ratios of the subsoil; I=1,  
              NC; see remarks under CO(I)
- CH          - constant coefficient of consolidation in  
              horizontal direction; in case of two  
              layers, CH applies to the upper layer;  
              dimension -  $ft^2/day$
- CHIN(I)     - variable coefficients of consolidation in  
              horizontal direction; I=1,  $ICV \leq 10$ ; stress-  
              dependent coefficients of consolidation  
              in horizontal direction are obtained  
              within subroutine COEF by interpolation  
              between the CHIN-values; dimension -  
               $ft^2/day$

- CV - constant coefficient of consolidation in the vertical direction; in case of two layers, CV applies to the upper layer; dimension -  $\text{ft}^2/\text{day}$
- CVIN(I) - variable coefficients of consolidation in the vertical direction;  $I=1$ ,  $ICV \leq 10$ ; stress-dependent coefficients of consolidation in the vertical direction are obtained within subroutine COEF by interpolation between the CVIN-values; dimension -  $\text{ft}^2/\text{day}$
- DMAX - maximum step size to be used in the variation of XC and YC in the search procedure for the minimum factor of safety; dimension - feet
- DMIN - minimum step size to be used in the variation of XC and YC in the search procedure for the minimum factor of safety; dimension - feet
- EO - initial void ratio; in the case of two layers, EO applies to the upper layer
- FSI - factor of safety which is required at the time of application of a new load
- GAMMA - effective unit weight of the subsoil, constant over the thickness of the compressible layer; this value is needed in the settlement computations using the compression index; if GAMMA=0, input of MYE effective overburden stresses at equally spaced depths must be input; dimension - pcf
- GLOAD - unit weight of the embankment soil, dimension - pcf
- GRID - symbol to be used in the resulting plots to mark the 10% coordinates; proposed to be the letter I
- H - thickness of the compressible layer; if  $H=0$ , the program is terminated;

if H=99, a branch is made to the beginning of the programs; dimension - feet

- HC - Henry's constant of gas solubility,  
HC=0.020 for atmospheric air,  
HC=0.029 for methane, HC=2.84  
for hydrogen sulfide (at 68°F)
- HI - thickness of the "impedance layer"  
underlying the compressible soil;  
the "impedance layer" must have a  
freely draining lower surface, a  
coefficient of compressibility which  
is negligibly small compared to that  
of the consolidating soil, and a  
permeability of the same order of  
magnitude as that of the consolidation  
soil; dimensions - feet
- IAB - identifier where -  
IAB=0 - Skempton's pore pressure coefficients  
A and B as defined for the last load  
are also used to compute the pore  
water pressures due to the load addition  
IAB=1 - redefine A and B
- IAV - identifier where -  
IAV=0 - use a constant coefficient of compress-  
ibility in the settlement computations  
IAV=1 - use the compression indices in the  
settlement computations
- IBCV - identifier where -  
IBCV=1 - impeded vertical drainage at the  
bottom of the consolidating layer  
IBCV=2 - free vertical drainage at the  
bottom of the consolidating layer  
IBCV=3 - no vertical drainage at the  
bottom of the consolidating layer
- ICV - number of data pairs (PCV(I),CVIN(I)) and  
(PCR(I),CRIN(I)) through which Lagrangean  
interpolation polynomials are passed;  
0 < ICV < 10
- IDEN(I) - identifier corresponding to the I-th load  
step, where

IDEN(1)<0 - the excess pore water pressures due to the first load step are set equal to the input residual pore water pressures  
IDEN(I)=0 - the excess pore water pressures due to the I-th load are computed by means of subroutine PORE  
IDEN(I)=1 - the excess pore water pressures due to the I-th load are set equal to those computed for the reference load. Note, that this requires that Skempton's coefficients A and B are identical in both cases;  
IDEN(1)<0 allows the check of an existing installation for which the excess pore water pressures just after load application are known from field measurements; I=1, NL

IEND - number of horizontal coordinates XT; IEND is computed, if ISP=0; IEND < 20

IK - identifier where  
IK=0 - constant coefficients of permeability  
IK=1 - the radial and vertical coefficients are variable; the void ratio versus the logarithm of the coefficient of permeability is a straight line

IRP - identifier where  
IRP=0 - no residual pore water pressures are input  
IRP=1 - residual pore water pressures at points (W\*XT, H\*YE) are input columnwise  
IRP=2 - residual pore water pressures at arbitrary points are input

ISAT - identifier where  
ISP=0 - settlements, the process of consolidation, and the stability are analyzed; in program SAND, the times at which a new load step can be applied are determined;  
ISP=1 - settlements and the process of consolidation are analyzed, and the times of load application are required as input parameters in program SAND; ISP=1 also requires the output of the time-dependent pore water pressures at MRE\*MYE

points of the solution domain of the sand drain installations with axes at the user-defined locations XT

- ITBL - number of times TB(I), defined in a DATA-statement, for which the pore water pressures and settlements are determined; times TB always start at the time of application of a new load step in SAND; ITBL  $\leq$  45
- IVAR - identifier where  
IVAR=0 - use constant coefficients of consolidation  
IVAR=1 - use variable coefficients of consolidation which are obtained either by interpolation between CHIN(I) and CVIN(I) or by varying the coefficient of compressibility and/or the coefficients of permeability
- JND - number of points for which output is required  
JND  $\leq$  10
- JSP(I) - indices of the JND points for which output is required; I=1, JND  $\leq$  10; the output is for points XE (JSP(I)), where XE and MX equally spaced coordinates between and including the limits W\*AX(1) and W\*AX(NI); for example, specification of JSP(1)=1 and JSP(JND)=MX causes the output of information at the limits W\*AX(1) and W\*AX(NI), respectively
- KHO - initial coefficient of permeability in the horizontal direction; dimension - ft/day
- LAYER - number which indicates the location of a layer interface; LAYER=KK means that the layer interface is located at a depth below ground surface which is equal to  $Y=H*(KK-1)/(MYE-1)$ ; if only one layer is to be considered, set LAYER=0; the program requires that  $3 \leq \text{LAYER} \leq (MYE-3)$ ; LAYER causes a layer interface to be considered in the consolidation and the settlement analyses only
- LND - number of weeks to be plotted on the time axis of the output figures
- MINP - number of points defining the contour of the embankment load; MINP  $\leq$  20



- MHE - number of equally spaced points in the horizontal direction; MHE  $\leq$  40
- MX - number of equally spaced points XE in the horizontal direction between the limits AX(1) and AX(NI); MX  $\leq$  51
- MXT(I) - number of unequally spaced points XT between the consecutive limits AX(I) and AX(I+1); I=1, (NI-1)  $\leq$  4; maximum value of any MXT(I) must be values MXT(I) must not exceed IEND=20
- MYE - number of equally spaced points in the vertical direction, including the surface and the bottom of the compressible layer; MYE  $\leq$  12
- NC - number of initial undrained shear strengths, CO(I), and  $(c/\bar{p})$ -ratios, CP(I); NC  $\leq$  MYE  $\leq$  11
- NI - number of interval limits AX(I); NI  $\leq$  5
- NL - number of load steps; NL  $\leq$  6
- NRAD - number of trial arcs to be used with each trial center (XC,YC) in the stability analysis; NRAD  $>$  1
- NS - number of load strips used to approximate the actual embankment load; NS  $\leq$  20
- P(I) - present overburden effective stresses at MYE equally spaced depths, including the surface; I=1, MYE  $\leq$  12; dimension - psf
- PC(I) - preconsolidation stresses at MYE equally spaced depths, including the surface; I=1, MYE  $\leq$  12; dimension - psf
- PCH(I) - effective stresses at which the horizontal coefficients of consolidation, CHIN(I), are defined; I=1, ICV  $\leq$  10; dimension - psf
- PCV(I) - effective stresses at which the vertical coefficients of consolidation, CVIN(I), are defined; I=1, ICV  $\leq$  10; dimension - psf

- PU           - initial pore gas pressure; if PU is not defined during input, it is set equal to the sum of the atmospheric pressure plus one-half the thickness of the compressible layer times the unit weight of water; dimension - psf
  
- RAV          - coefficient of compressibility of the lower layer divided by that of the upper layer
  
- RC           - vertical coefficient of consolidation of the lower layer divided by that of the upper layer
  
- RCC          - virgin compression index of the lower layer divided by that of the upper layer
  
- REO          - initial void ratio of the lower layer divided by that of the upper layer
  
- RK           - vertical coefficient of permeability of the lower layer divided by that of the upper layer  
             note, if RC and RAV are specified,  
              $RK = RC * RAV * (1 + EO) / (1 + EO * REO)$
  
- RKV          - vertical coefficient of permeability of the consolidating soil divided by that of the underlying impedance layer
  
- ROC          - recompression index divided by the virgin compression index; in case of two layers, ROC applies to the upper layer
  
- ROCL         - recompression index of the lower layer divided by the virgin compression index of the upper layer
  
- S            - degree of saturation to be input as a decimal fraction
  
- SKH          - slope of the void ratio versus the logarithm of the horizontal coefficient of permeability curve
  
- SKV          - slope of the void ratio versus the logarithm of the vertical coefficient of permeability curve
  
- SPECS        - fraction of the consolidation settlement due to the reference load; this settlement must have occurred before a new load is applied (program SAND)
  
- SPECU        - when the non-dissipated average pore water pressures become less than 5% of the total average

pore water pressures existing just after application of the last load at IEND\*SPECU points XT, subsequent loads are disregarded; the rationale for this procedure is that no significant increase in strength and/or settlement can be expected after an average degree of consolidation of 95% has been reached under the applied load at a number of points; in selecting the magnitude of SPECU, which is input as a decimal fraction, it should be noted that the degrees of consolidation in the case of constant coefficients of consolidation will be the same for different points XT, as long as the drainage boundary conditions are the same

- STAR - symbol to be used in the resulting plots to mark the coordinate axes; proposed to be the asterisk \*
- SYMB(I) - symbols to be used in the resulting plots to present points of the computed curves; the letters U, C, O, and T are proposed for the average degree of consolidation, the consolidation settlement, the initial, and the total settlement versus time curves, respectively. It should be noted that T plots on top of O, which plots on top of C, which plots on top of U; this means, that only T will show, when the four values are identical; I=1,2 in the case of complete saturation, and I=1,4 in the case of partial saturation  
User can use any other letters as symbols
- TA - available construction time; in SAND, this is the time at which the final load must have been applied; dimension - days
- TGPHI - tangent of the angle of internal friction of the drainage blanket, if there is one
- TL(I) - times of load application in the case where ISP=1; I=1, NL ≤ 6; dimension - days
- TMIN - time which must have passed after a load application before the first stability analysis is made to determine, whether the next load can be applied; dimension - days
- U\* - residual pore water pressure; dimension - psf

- W - reference value in the horizontal direction;  
dimension - feet
- X\* - horizontal distance from the center line at which  
the residual pore water pressure is known;  
dimension - feet
- XC - X-coordinate of the center of the first trial arc;  
if XC=0 is input, the programs select a starting  
value; dimension - feet
- XINP(I) - X-coordinates of the points defining the embank-  
ment contour; I=1, MINP < 20; dimension - feet
- XT(I) - X-coordinates of the points at which the settle-  
ments and the consolidation behavior are deter-  
mined; if ISP=0, XT(I) are computed for I=1  
through MXT(J); if ISP=1, XT(I), I=1, IEND < 20  
are input as fractions of W
- Y\* - vertical distance below the ground surface at  
which the residual pore water pressure U is known;  
positive downward; dimension - feet
- YC - Y-coordinate of the center of the first trial arc;  
positive upward; dimension - feet
- YINP(I) - Y-coordinates of the points defining the embank-  
ment contour; positive upward; I=1, MINP < 20;  
dimension - feet
- YWM - thickness of a drainage blanket placed on the  
surface of the compressible soil layer; dimension  
- feet
- ZZ - distance between the maximum YINP(I) and the  
minimum value YC permissible in the stability  
analyses; dimension - feet

---

\* The residual pore water pressures are first arranged such that points having the same X-coordinate are grouped in the order of ascending Y-coordinates. Data sets are then input in the order of ascending X, whereby the last card is identified by COUNT ≠ 0.

## Method

The programs facilitate the analysis of an embankment foundation on a soft, compressible soil layer, which is underlain by a firm stratum. The approach involves the consideration of the following problems: (a) stress and pore pressure distribution within the soft layer due to a symmetrical vertically acting embankment load at the surface, (b) the dissipation of excess pore water pressures subject to different flow conditions including horizontal flow, (c) the computation of settlements, and (d) the stability of the embankment-subsoil system with consideration of the gain in shear strength as consolidation proceeds.

The programs are designed to solve several cases during the same program execution, wherefore some computations are performed before data for a specific case are input. To save computer time and storage, computations are only done for a limited number of locations in the horizontal direction, and information at intermediate points is obtained by interpolation.

PROGRAM SAND -- After computation of the pore water pressures and settlements due to a reference load, which in most cases will be identical with the final load, essentially two options are available by means of index ISP. If  $ISP=0$ , the embankment contours of the different load steps are input and the program determines the times at which new load steps can be applied. The criteria incorporated into the programs are: (1) a defined portion of the reference settlement at the point closest to the center line of the embankment must have occurred, and/or

(2) a specified factor of safety must be assured at the time of a new load application. To avoid unnecessarily numerous stability analyses stability analyses, a time TMIN measured from the last load application can be defined, and stability analyses are not performed for times less than TMIN, although settlements and degrees of consolidation are computed. For the same reason, the program contains the restriction that all subsequent load steps are disregarded if 95% consolidation has occurred at a specified number of points under the acting load. The rationale is that only a minor increase in strength and settlements can be expected due to dissipation of the remaining excess pore water pressures, and the times required will likely be prohibitive.

If  $ISP=1$ , the different load contours, as well as the times of load application, must be input, and the program analyzes the consolidation process and the settlements without performing any stability analyses. Use of  $ISP=1$  also produces the output of the pore water pressures at  $MYE \cdot IEND$  points of a vertical cut through the locations  $XT \cdot W$ .

The computed information is first stored internally on two internal files for each step of load. A total of 6 steps of loads are allowed.

The program can handle analysis of multiple embankments in a single run. This is done by putting  $H = 99$  at the end of the data cards for the previous embankment. On the other hand by specifying  $H = 0$  the program is terminated.

The output, in addition to that given for  $ISP=0$ , includes the excess pore water pressures at  $MYE \cdot JND$  points of a vertical section through the subsoil.

#### Remarks

The average degree of consolidation is defined in the programs as the integral over the dissipated pore water pressures divided by the integral over the excess pore water pressure build-up under the reference load.

The increase in the effective stresses at the time of load application in the case of a partially saturated soil is assumed to be equal to the difference between the pore water pressures obtained for  $B=1.0$  and  $B<1.0$ , where  $B$  is Skempton's pore pressure coefficient.

To account for the fact that the swelling index is normally considerably smaller than the compression index, negative pore water pressures, which might result after surcharge removal, are neglected in program SAND.

#### Subroutines Required

COEF (UAVD,UAVE,OMEGA,PHI,LI,IL,OMED,PHID,NN)  
DISP (U,LI,OMEGA,PHI,T,UAVE,LIFT,MYE,IEND,XT,SV)  
GAIN (UA,R,SU,MYE,MXT,MXE,MX,NIM,CO,CP,III)  
GENS (S,M)  
INIT (XINP,YINP,MINP,XC,YC,YY,ZZ,DMIN)  
LAGR (X,Y,M,JST,XX,YY,N)

```
MATR (IS,IE,M,XV,A,XM)
MINV (A,N,D)
MPRD (A,B,R,N,M,L,IAS,IBS,IRS)
PORE (XINP,YINP,M,NST,CX,IX,CY,IY,U,ABAR,BBAR)
SETL (U,SETTL,IEND,KKK,MYE,F,FUP,FLO,KIAV)
STAB (XC,YC,R,XINP,YINP,MINP,MX,MYE,SU,FX,D,DM,YY)
```

## 2.2 Subroutine APROX

### Purpose

To approximate the embankment contour by a number of strips of constant thickness

### Usage

```
CALL APPROX (X,Y,MN,N,D)
```

### Block Names

```
POAPI/ALPHA(30),L
```

### Description of Parameters

X,Y - coordinates of the points defining the embankment contour; must be provided such that  
X(1)=0<X(2)<.....<X(MN)

MN - number of points X,Y; MN ≤ 20

N - number of approximating strips

D - thickness of the approximating strip

ALPHA - returned lengths of the strips

L - number of values ALPHA, L ≤ 30

### Statement Functions Required

```
CONK(KO,SKM);VARK(KO,SKM);PSI(AA,K)
```



### 2.3 Subroutine DETFS

#### Purpose

To determine the factor of safety of an embankment resting on a soft subsoil.

#### Usage

```
CALL DETFS(XC,YC,R,XINP,YINP,MINP,MX,MYE,SU,FS)
```

#### Block Names

```
INDET/RHO(19),TAU(19),PSI(19)  
SAPOD/IOUTP*;W*;H*;GLOAD,CLOAD,NARC,NRAD*  
SADET/XSTAB(51),YSTAB(11),DX,DY,YWM,TGPHI  
* Parameters marked by an asterisk are not needed in this  
  subroutine
```

#### Description of Parameters

XC	- X-coordinate of the center of the circular slip surface
YC	- corresponding Y-coordinate
R	- radius of the circular slip surface
XINP	- X-coordinates of the points defining the embankment contour
YINP	- corresponding Y-coordinates
MINP	- number of points (XINP,YINP)
MX	- number of equally spaced grid points in the X-direction

MYE        - number of equally spaced grid points in the Y-direction

SU         - undrained shear strengths at (MX\*MYE) grid points

FS         - factor of safety to be provided

RHO        - slopes of the lines connecting consecutive points XINP/YINP

TAU        - parameters defined in subroutine INIT;  $TAU=1+RHO^2$

PSI        - Y-value at X=0 for the lines connecting consecutive points XINP/YINP

GLOAD      - unit weight of the embankment soil

CLOAD      - undrained strength of the embankment soil

NARC       - one-half the number of subarcs within the subsoil

XSTAB      - X-coordinates of the grid points

YSTAB      - Y-coordinates of the grid points

DX         - interval in the X-direction

DY         - interval in the Y-direction

YWM        - thickness of the drainage blanket

TGPHI      - tangent of the angle of internal friction of the soil in the drainage blanket

### Method

A total stress analysis is performed to evaluate the factor of safety of an embankment which consists of cohesive soil and a cohesionless drainage blanket. The undrained strengths of the subsoil are input at MX\*MYE grid points, and the strength available along the portion of the circular slip surface that passes through the subsoil is obtained at the centers of 2\*NARC subarcs

by interpolation between the strengths SU at adjacent grid points. Resisting the driving moments are first computed with the assumption that the embankment consists entirely of frictionless soil. The so-obtained ratio of moments is then used as the initial estimate in the iteration for the correct factor of safety, in which the drainage blanket is considered.

#### Statement Functions Required

FUNA (A,B), FUNB (B), FUNC (A,B,C)

#### Remarks

The coordinates YINP,YC,YWM and PSI are positive upward, wherein YSTAB is positive downward with the coordinate origin at the surface of the soft layer.

#### 2.4 Subroutine DISP

#### Purpose

To determine the excess pore water pressures at arbitrary times for step loading conditions.

#### Usage

CALL DISP(U,LI,OMEGA,PHI,T,UAVE,LIFT,MYE,IEND,XT,SV)

#### Block Names

SAPOD/IOUTP,W\*,H\*,GLOAD\*,CLOAD\*,NARC\*,NRAD\*;  
SADI1/LAYER,IBCV,MHE,M,N,IDC,NDR,ISUM,XET(41);

SADI2/FIMPV,RC,RK,C,RO,RE,TA,ISP,IVAR;

\* parameters marked by an asterisk are not needed in this subroutine

### Description of Parameters

- U           - pore water pressures to be determined; for LI=1,5,6 this vector contains the additional pore water pressures for the new load, when subroutine DISP is called
  
- LI=1       - determines vectors A and B for the load addition
  
- LI=2       - determines the pore water pressures due to step-wise constant loads
  
- LI=3       - determines vectors A and B for times between load applications in the case where the "consolidation factor" is variable
  
- LI=5       - first lift; first execution of subroutine DISP
  
- OMEGA      - "consolidation factors" for radial flow; product of the gas factor and the radial coefficient of consolidation
  
- PHI        - "consolidation factors" for vertical flow; product of the gas factor and the vertical coefficient of consolidation
  
- T          - time
  
- UAVE       - average pore water pressures
  
- LIFT       - number of lifts applied at and before time T
  
- MYE        - number of points equally spaced in the vertical direction at which the pore water pressures are computed
  
- MHE        - number of points equally spaced in the horizontal direction at which the pore water pressures are computed < 40
  
- IEND       - number of elements in vectors OMEGA,PHI,UAVE and XT

XT            - points in the horizontal direction for which OMEGA  
              and PHI are input and UAVE is computed

SV            - mathematical molecule of the extended Simpson's  
              or trapezoidal rules in the vertical direction

IOUTP        - logical output unit

LAYER        - index indicating the depth of a layer interface;  
              LAYER > 3

IBCV=1      - vertical drainage; impeded drainage at the lower  
              boundary surface

IBCV=2      - vertical drainage; free drainage at the lower  
              boundary surface

IBCV=3      - vertical drainage; no drainage at the lower bound-  
              ary surface

M            - number of eigenvalues for the vertical problem

N            - number of eigenvalues for the horizontal problem

IDC=1        - vertical flow only at all points XT

IDC=2        - vertical plus horizontal flow at all points XT

ISUM        - number of elements of vector U

FIMPV        - "impedance factor" for vertical flow; FIMPV=  
              (RKV\*HI/DY) / (1.+RKV\*HI/DY), as defined in SAND

RC           - ratio of the vertical coefficients of consolidation  
              of the lower and upper layer

RK           - ratio of the vertical coefficients of permeability  
              of the lower and upper layer

ISP=1        - compute and print the pore water pressures at all  
              MYE\*MRE points of the solution domain for IEND  
              locations XT; return the averages taken at MYE  
              depths over the circular area of influence as  
              vector U; return the overall average at IEND  
              locations XT as vector UAVE

ISP=0        - suppress the printing

IVAR=0    - constant "consolidation factors"  
IVAR=1    - variable "consolidation factors"

#### Method

The consolidation problem is treated as an eigenvalue problem.

#### Subroutines Required

EFGEN(PSI,T,EIG,IVAR,MM,NN,D,LI)  
MAMUL(A,D,B,C,N,IS,II)  
MODAL(LAYER,IBC,N,FIMP,RC,RK,XO,XE,EIG,X,XI,F)  
MPRD(A,B,R,N,M,L,IAS,IBS,IRS)

#### Remarks

Storage reservations are made to account for IEND  $\leq$  40 and a maximum of 6 step loads.

### 2.5 Subroutine LINT

#### Purpose

To interpolate between arbitrarily spaced data points by use of interpolation or extrapolation.

#### Usage

Call LINT(X,Y,N1,M,XX,YY,N)

### Description of Parameters

- X - vector of arguments for which the values of the function are interpolated
- Y - resulting vector of interpolated values of the function
- N1 - number of arguments in X
- M - index of the last value of Y
- XX - vector of arguments for which the values of the function are known
- YY - vector of known values of the function
- N - number of arguments in XX

## 2.6 Subroutine HDIST

### Purpose

To calculate the horizontal distance from the CL to the point where the pore pressure is 0.1% of the maximum pore pressure under the embankment.

### Usage

Call HDIST(UB,XT,IEND,ICV,CHIN,DXSQ,AAH,MHE,W,  
XET,IPOR,HF,MYE,POR)

### Description of Parameters

- UB - pore pressure at (MYE\*IEND) points under the embankment
- XT - X-coordinate of the points at which the settlements and consolidation behavior are determined
- IEND - number of horizontal coordinates XT

ICV - number of data pairs (PCV(I),CVIN(I)) and (PCH(I),CHIN(I)) through which Lagrangian interpolation polynomials are passed

CHIN - variable coefficient of consolidation in horizontal direction

DXSQ - (DELTA H\*\* 2.)

AAH - (1.+EO)/(GAMMA WATER x (DELTA H) \*\* 2.)

MHE - number of horizontal grid points

W - Reference width

XET - X-coordinates of the equidistant points in the horizontal direction

IPOR - indicator to specify the value of POR  
 =1 , POR is specified by the user  
 =0 , program evaluates POR

HF - =1 , If horizontal flow is considered  
 =0 , If no horizontal flow is allowed

MYE - number of points in the vertical direction

POR - horizontal drainage distance/[XT(IEND)\*W]

## 2.7 Subroutine COEF

### Purpose

To determine the gas factor and the coefficients of consolidation.

### Usage

COEF-UAUD,UAVE,OMEGA,PHI,LI,IL,OMED,PHID,NN]

### Block Names

SACSE/ROC,ROCL,SVM,P,PC,PLOQ,PO,PCO,LAV,IK,ISAT,AAV,AAH  
 SAC01/AVO,KVO,KHO,EOPUS,PU,SKHM,SKVm,CCC,NNN,ICOEFF  
 SAC02/PCV(10),CXIN(10),PCR(10),CHIN(10),ICV,KOUNT,HF



Description of Parameters

UAVD	- average pore pressure before consolidation
UAVE	- average pore pressure at some time after consolidation
OMEGA	- consolidation factors of horizontal flow, product of the gas factor and the horizontal coefficient of consolidation
PHI	- consolidation factor for vertical flow, product of the gas factor and the vertical coefficient of consolidation
IL	- indicator =1 - calculate the parameters for vertical flow #1 - calculate the parameters for horizontal flow
LI	- identifier; if LI=3, OMED and PHID are computed
NN	- number of points where OMEGA,PHI,OMED and PHID are required
OMED	- difference between the radial consolidation factor computed in a previous execution of this subroutine and the value computed in this execution of the subroutine
PHID	- difference between the vertical consolidation factor computed in a previous execution of this subroutine and the value computed in this execution of the subroutine
IEND	- number of elements in arrays UAVD,UAVE,OMEGA,PHI,OMED,PHID
ROC	- ratio between the recompression and the virgin compression indices
PO	- average initial vertical effective stress
PCO	- average preconsolidation stress
IAV=0	- constant coefficient of compressibility

IAV=1        - variable coefficient of compressibility

IK=0        - constant coefficient of permeability

IK=1        - variable coefficient of permeability

ISAT=0      - 100% saturation

ISAT=1      - partial saturation

AAV        - factor defined in program SAND;  $AAV=(1+EO)/(62.43*DY^2)$

AAH        - factor defined in program SAND;  $AAH=(1+EO)/(62.43*DH^2)$

AVO        - initial or constant coefficient of compressibility

KVO        - initial coefficient of permeability in the vertical direction

KRO        - initial coefficient of permeability in the radial direction

EOPUS      - factor defined in program SAND;  
             $EOPUS=EO*PU*(1-S)*(1-HC)$

PU        - initial pore gas pressure

SKVM      - factor defined in program SAND;  $SKVM=CC/SKV$ , if  
            IAV=1 and  $SKVM=2.3026*AVO/SKV$ , if IAV=0

SKHM      - factor defined in program SAND;  $SKHM=CC/SKH$ , if  
            IAV=1 and  $SKRM=2.3026*AVO/SKH$ , if IAV=0

CCC        - compression index times 0.4343

NNN        - number of locations with radial and vertical drainage conditions

ICOEF=1    - IK=0, IAV=0 or IAV=1

ICOEF=2    - IK=1, IAV=0

ICOEF=3    - IK=1, IAV=1

ICOEF=4    - the coefficient of consolidation is obtained by interpolation

PCV            - effective stresses for which the vertical coefficients of consolidation are input

CVIN          - vertical coefficients of consolidation at PCV

PCH           - effective stresses for which the radial coefficients of consolidation are input

CHIN          - radial coefficients of consolidation at PCH

ICV           - number of PCV, CVIN, PCR, and CRIN; ICV < 10

KOUNT=0      - second or subsequent executions of this subroutine

KOUNT=1      - first use of this subroutine

#### Method and Reference

Depending on the values of the indices ISAT, IK, IAV, and ICOEF, the values of the "consolidation factors" for radial and vertical flow are determined for the average increases in effective stresses (UAVD-UAVE) at IEND locations. Relationships considered include: (bi-) linear void ratio versus logarithm of effective stress or constant coefficient of compressibility; linear void ratio versus logarithm of coefficient of permeability; and arbitrary coefficient of consolidation versus effective stress relationships.

#### 2.8 Subroutine EFGEN

##### Purpose

To generate the time-dependent matrix D.

##### Usage

CALL EFGEN(PSI,T,EIG,IVAR,MM,NN,D,LI)

### Description of Parameters

PSI        - vector containing MM "consolidation factors"

T         - time at which diagonal matrix D is computed

EIG       - vector containing the eigenvalues

IVAR=0    - constant "consolidation factor"; PSI consists of  
           one element only

IVAR=1    - variable "consolidation factor"; PSI consists of  
           MM elements

MM        - number of elements PSI (in most other routines,  
           this parameter is called IEND)

NN        - number of eigenvalues

D         - diagonal matrix to be determined

### Method

The elements of the diagonal matrix D are given by  $\exp(\text{PSI}(J) * \text{EIG}(I) * T)$ , wherefore D has a total of  $MM * NN$  elements. However, if  $IVAR=0$ ,  $D(K) = D(K+NN) = \dots = D(K + (MM-1) * NN)$ .

### 2.9 Subroutine GAIN

#### Purpose

To determine the gain in shear strength.

#### Usage

CALL GAIN(UA,R,SU,MYE,MXT,MXE,MX,NIM,CO,CP,III)

### Description of Parameters

- UA        - vector of dissipated pore water pressures at points (XT,XE)
- R         - auxiliary matrix necessary to compute the dissipated pore water pressures at points (XE,YE) from a knowledge of those at points (XT,YE)
- SU        - resultant undrained strengths at points (XE,YE)
- MYE       - number of equally spaced points in vertical direction
- MXT(I)    - number of points XT between the interval limits AX(I) and AX(I+1)
- MXE(I)    - number of points XE between the interval limits AX(I) and AX(I+1)
- MX        - sum of MXE(I) for I=1,NIM
- NIM       - number of subintervals
- CO        - vector containing MYE undrained initial shear strength values
- CP        - vector containing MYE  $(c/\bar{p})$ -ratios
- III=1     - all elements of array UA are assumed to be equal to zero
- III=0     - some or all elements of array UA differ from zero

### Method

The strength values SU are obtained as the sum of the initial shear strengths plus the products of the  $(c/\bar{p})$ -ratios and the dissipated pore water pressures.

#### 2.10 Subroutine FUNCT

### Purpose

This subroutine computes the values of the integrands for the argument theta.

### Usage

```
CALL FUNCT(THETA,ETA,K,SIGX,SIGY,TAU)
```

### Block Names

```
POFUN/Q(258),ETHST(258)
```

### Description of Parameters

- |      |  |
|------|--|
| K    | - index necessary to select the proper quantities Q and ETH, which have been precomputed for the same argument THETA |
| SIGX | - value of the integrand of the equation for the horizontal normal stress  |
| SIGY | - value of the integrand of the equation for the vertical normal stress  |
| TAU  | - value of the integrand of the equation for the shear stress  |
| Q    | - precomputed vector whose elements are equal to the sum of $(\sin \alpha_1 \theta)/\theta$                          |
| ETH  | - precomputed vector whose elements are equal to $\exp(\theta)$  |

### Method

The subroutine makes use of the fact that the hyperbolic sine and cosine functions can be expressed in terms of the exponential function.

## 2.11 Subroutine GENER

### Purpose

To determine the coefficients and the roots of the characteristic equation.

### Usage

```
CALL GENER(P,F,X,N)
```

### Description of Parameters

- P - tridiagonal matrix whose lower off-diagonal elements are equal to -1.0
- F - auxiliary matrix used during the computations
- X - roots of the characteristic equation; these are the eigenvalues
- N - degree of the characteristic equation

### Subroutines Required

```
RROOT (A,X,N)
```

## 2.12 Subroutine GENS

### Purpose

To generate the mathematical molecules which are used in a numerical integration.

### Usage

```
CALL GENS(S,M)
```

### Description of Parameters

S - resulting mathematical molecule  
M - number of pivotal points

### Method

For the case of vertical flow, the elements of vector S are either computed by the extended Simpson rule or the extended trapezoidal rule assuming equal spacing; the use of Simpson's rule requires that M be an odd number.

### 2.13 Subroutine INIT

#### Purpose

To select starting values for the stability analysis and define three vectors which are repeatedly used in subroutine DETFS.

#### Usage

CALL INIT(XINP,YINP,MINP,XC,YC,YY,ZZ,DMIN)

#### Block Names

SAPOD/IOUTP\*,W\*,H,GLOAD\*,CLOAD\*,NARC\*,NRAD\*;  
INDET/RHO(19),TAU(19),PSI(19);  
\* parameters marked by \* are not needed in this routine



### Description of Parameters

XINP - X-coordinates of the points defining the embankment contour

YINP - Y-coordinates of the points defining the embankment contour

MINP - number of points (XINP,YINP)

XC - X-coordinate of the center of the first trial slip surface

YC - corresponding Y-coordinate

YY - minimum permissible value for YC

ZZ - difference between the maximum YINP-value and YY

DMIN - minimum increment to be used in the direct search procedure

H - thickness of the compressible layer

RHO - slopes of the lines which connect consecutive points (XINP,YINP)

TAU -  $TAU=1+RHO**2$

PSI - Y-value at X=0 for the lines connecting consecutive points (XINP,YINP)

### Method

When the center of the first trial failure arc is not input from SAND, YC is set equal to YY and XC is defined as one-half of the sum of the X-values obtained when two circles with radius  $R=YY+H$  pass through (XINP(1),YINP(1)) and the toe of the embankment, respectively. The vectors RHO, TAU, and PSI are computed once for repeated use in subroutine DETFS

## 2.14 Subroutine INTEG

### Purpose

To compute approximate values of the stress integrals between the limits B and infinity.

### Usage

```
CALL INTEG(ETA,XI,B,AR)
```

### Block Names

```
PCAPI/ALPHA(30), L;
```

### Description of Parameters

ETA	- Y-coordinate divided by the thickness of the compressible layer
XI	- X-coordinate divided by the thickness of the compressible layer
B	- lower integration limit
AR	- resulting array with six integral values
ALPHA	- length of the load strips divided by the thickness of the compressible layer
L	- number of ALPHA's

## 2.15 Subroutine LAGR

### Purpose

To interpolate between arbitrarily spaced data points by use of the Lagrangean polynomial.

### Usage

```
CALL LAGR(X,Y,M,JST,XX,YY,N)
```

### Description of Parameters

X        - vector of arguments for which the values of the  
          function are interpolated

Y        - resulting vector of interpolated values of the  
          function

X        - number of arguments X

JST      - index of the first value Y to be interpolated

XX       - vector of arguments for which the values of the  
          function are known

YY       - vector of known values of the function

N        - number of arguments XX

### Method

A Lagrangean polynomial of degree (N-1) is passed through the data points (XX,YY) and then evaluated for M arguments X. See, for example, the book by CARNAHAN, LUTHER, AND WILKES (1969).

#### 2.16 Subroutine MAMUL

### Purpose

To perform the matrix multiplication: (general matrix)\*(diagonal matrix)\*(column vector).

### Usage

CALL MAMUL(A,D,B,C,N,IS,II)

### Description of Parameters

- A - general square matrix
- D - diagonal matrix
- B - column vector
- C - resulting column vector
- N - order of matrices A and D and length of vectors B and C
- IS - index of the first element of vector B
- II - index of the first element of matrix D, whose diagonal elements only are stored one-dimensionally

### Method

The subroutine utilizes the fact that all matrices are stored one-dimensionally, so that the I-th element of vector C becomes

$$C(I) = \sum_{K=1}^N A(I+K \cdot N - N) * B(IS-1+K) * D(II-1+K)$$

#### 2.17 Subroutine MATR

### Purpose

To generate matrix XM, the elements of whose rows are equal to integer powers of the differences between the elements of vector XV and constant A.

### Usage

```
CALL MATR(IS,IE,M,XV,A,XM)
```

### Description of Parameters

IS    - index of the first element of vector XV  
IE    - index of the last element of vector XV  
M     - number of rows of matrix XM  
XV    - vector with (IE-IS+1) elements  
A     - constant to be subtracted from all elements XV  
XM    - resulting M by (IE-IS+1) matrix

### Method and Reference

Given the vector XV with elements  
XV(IS),XV(IS+1),...,XV(IE), the M by (IE-IS+1) matrix is generated and stored one-dimensionally, such that  $XM(K+I*M-M) = (XV(IS+I-1) - A) ** (K-1)$ .

### Program Length

45 words

### 2.18 Subroutine MINV

### Purpose

To invert a general matrix.

### Usage

CALL MINV(A,N,D)

### Block Names and Lengths

None

### Description of Parameters

- A - input matrix destroyed in computation and replaced by the resultant inverse
- N - order of matrix A;  $N \leq 25$
- D - resulting determinant

### Method and Reference

The standard Gaub-Jordan method is used. This subroutine is a slightly modified version of subroutine MINV, as given in the IBM Application Program, 1130 Scientific Subroutine Package (1130-CM-02X), Programmer's Manual, Form H20-0252-0, White Plains, New York, 1966.

2.19 Subroutine MODAL

### Purpose

To determine matrix P, its eigenvalues, the corresponding modal matrix, and the inverse of the modal matrix.

### Usage

```
CALL MODAL(LAYER,IBC,N,FIMP,RC,RD,XO,XE,EIG,X,XI,F)
```

### Description of Parameters

LAYER=1	- radial drainage conditions
LAYER=2	- vertical drainage conditions; homogeneous soil profile
LAYER > 3	- vertical drainage conditions; two-layered soil profile with layer interface at YE(LAYER)
IBC=1	- vertical flow; impeded drainage at the bottom
IBC=2	- vertical flow; free drainage at the bottom
IBC=3	- vertical flow; no drainage at the bottom
N	- number of eigenvalues
FIMP	- "impedance factor"; for vertical flow ( $RKV \cdot HI / DY$ ) / ( $1 + RKV \cdot HI / DY$ )
RC	- ratio of the vertical coefficients of consolidation of the lower and the upper layers
RK	- ratio of the vertical coefficients of permeability of the lower and the upper layers
XO	- lower boundary of the solution domain
XC	- upper boundary of the solution domain
EIG	- resultant eigenvalues
X	- resultant modal matrix

XI                - inverse of the resultant model matrix  
F                - auxiliary matrix

### Method and Reference

For IBC=2 and IBC=3, the eigenvalues and the modal matrix can be computed directly for a homogeneous soil profile. In all other cases, the auxiliary matrix D and matrix P, whose eigenvalues are determined in subroutine GENER, must be generated before the modal matrix X can be set up. Finally, the inverse of the modal matrix is computed by use of subroutine MINV.

### Subroutines Required

GENER(P,F,X,N)  
MINV(A,N,D)

### Remarks

The lower off-diagonal elements of matrix P, which are equal to -1.0, are not stored.

## 2.20 Subroutine MPRD

### Purpose

To multiply two matrices to form a resultant matrix.

### Usage

CALL MPRD(A,B,R,N,M,L,IAS,IBS,IRS)



### Description of Parameters

A        - first input matrix  
B        - second input matrix  
R        - output matrix  
N        - number of rows of matrices A and R  
M        - number of columns of matrix A and number of rows  
          of matrix B  
L        - number of columns of matrices B and R  
IAS      - index of the first element of matrix A  
IBS      - index of the first element of matrix B  
IRS      - index of the first element of matrix R

### Method

The M by L matrix B is premultiplied by the N by M matrix A and the result is stored in the N by L matrix R. The indices IAS, IBS, and IRS allow the multiplication of submatrices of A and B, and the product is stored as a submatrix of R.

### Remarks

Matrix R cannot be in the same location as matrices A or B.

## 2.21 Subroutine PORE

### Purpose

To compute the elastic stresses and pore water pressures within a layer of finite thickness for a symmetrical vertical load.

### Usage

```
CALL PORE(XINP,YINP,M,NST,CX,IX,CY,IY,U,ABAR,BBAR)
```

### Block Names

```
SAPOD/IOUTP,W,H,GLOAD,CLOAD*,NARC*,NRAD*  
POAPI/ALPHA(30),L;  
POFUN/QST(129),ETHST(129);
```

\* parameters marked by an asterisk are not needed in this subroutine

### Description of Parameters

XINP	- X-coordinates of the points defining the embankment contour
YINP	- corresponding Y-coordinates
M	- number of points (XINP,YINP)
NST	- number of approximating load strips
CX	- X-coordinates divided by the reference value W, for which the stresses are to be computed
IX	- number of CX-values
CY	- Y-coordinates divided by the thickness of the compressible layer H, for which the stresses are to be computed
IY	- number of CY-values
U	- resulting excess pore water pressures (IX*IY < 220 elements)
ABAR	- Skempton's pore pressure coefficient A
BBAR	- Skempton's pore pressure coefficient B
IOUTP	- logical output unit

W            - reference length in X-direction  
H            - thickness of the compressible layer  
GLOAD       - unit weight of the embankment soil  
ALPHA       - lengths of the load strips which approximate the  
             actual embankment load  
L            - number of values ALPHA  
QST          - resulting vector whose elements are repeatedly  
             used in subroutine FUNCT  
ETH          - resulting vector whose elements are repeatedly  
             used in subroutine FUNCT

#### Method and Reference

The total stresses within a compressible layer are computed by use of elastic theory for plane strain conditions and a symmetric vertical loading. Poisson's ratio is set equal to 0.5, and the underlying stratum is assumed to be rough and rigid. Because of the complex nature of the stress integrals, a numerical integration procedure, based on either Simpson's rule or Filon's formulae, has been chosen for their evaluation.

#### Subroutines Required

APROX(X,Y,MN,N,D)  
FUNCT(THETA,ETA,K,SIGX,SIGY,TAU)  
INTEG(ETA,XI,B,AR)

#### Remarks

The coordinates YINP are positive upward, whereas ETO is positive downward with the coordinate origin at the surface of the compressible layer. ETA is positive upward with the origin at the bottom of the compressible layer.

## 2.22 Subroutine RROOT

### Purpose

To compute the real roots of the characteristic equation.

### Usage

CALL RROOT(COF,XR,M)

### Description of Parameters

COF    - input vector containing the (M+1) coefficients of  
         the polynomial

XR     - resulting M roots of the polynomial

M      - degree of the polynomial

## 2.23 Subroutine SETL

### Purpose

To compute settlements for constant or variable coefficients  
of compressibility.

### Usage

CALL SETL(U,SETTL,IEND,KKK,MYE,F,FUP,FLO,KIAV)

### Block Names and Lengths

SACSE/ROC,ROCL,SVM,P,PC,PLOG,PO\*,PCO\*,IAV\*,IK\*,ISAT\*,AAV\*,AAH  
\* parameters marked by an asterisk are not needed in  
this subroutine

### Description of Parameters

U	- input vector of dissipated pore water pressures with (MYE*IEND) elements
SETTL	- resulting vector of settlements
IEND	- number of elements of SETTLE
KKK	- number of points in the upper layer in the vertical direction
MYE	- total number of points in the vertical direction
F	- multiplying factor; if $F=1.0$ , the consolidation settlements are computed; if $F=1/B$ , where B is Skempton's pore pressure parameter, total settlements are computed
FUP	- parameter for the upper layer; contains the soil parameters
FLO	- parameter for the lower layer; contains the soil parameters
KIAV=1	- a constant coefficient of compressibility is used
KIAV=2	- a variable coefficient of compressibility is used
ROC	- ratio between the recompression and the virgin compression indices for the upper layer
ROCL	- recompression index of the lower layer divided by the virgin compression index of the lower layer
SVM	- modified mathematical molecule for integration in the vertical direction with MYE or (MYE+1) elements
P	- present overburden effective stress at MYE points
PC	- preconsolidation stresses at MYE points
PLOG	- natural logarithm of the ratio between the pre-consolidation and the overburden stresses

## Method

The computations are performed first for the upper layer; then, the displacements of the lower layer are evaluated by making the same computations with redefined parameters. A lower layer must be considered only if  $KKK < MYE$ .

## 2.24 Subroutine STAB

### Purpose

To search automatically for the minimum factor of safety.

### Usage

```
CALL STAB(XC,YC,R,XINP,YINP,MINP,MX,MYE,SU,FX,D,DM,YY)
```

### Description of Parameters

XC	- X-coordinate of the center of the circular slip circle
YC	- corresponding Y-coordinate
R	- radius of the circular slip surface
XINP	- X-coordinates of the points defining the embankment contour
YINP	- corresponding Y-coordinates
MINP	- number of points (XINP,YINP)
MX	- number of equally spaced grid points in horizontal direction

MYE     - number of equally spaced grid points in the  
          vertical direction

SU       - undrained shear strengths at (MX\*MYE) grid points

FX       - resulting factor of safety

D        - maximum step size to be used in the search  
          procedure

DM       - minimum step size to be used in the search  
          procedure

YY       - minimum permissible value for YC

#### Method and Reference

The programmed method embraces two tactical manoeuvres, the "exploratory move" and the "pattern move". Starting from the input base point (XC,YC), an exploratory move is made by varying first XC and then YC. If this move is successful, a pattern move is performed, followed again by a pattern move, if it was successful, and by an exploratory move, if it was not successful. This procedure is repeated until the minimum has been detected, whereafter the step size, by which XC and YC are varied, is decreased. When the minimum factor of safety is found by use of the smallest step size, DM, it is checked to determine whether the corresponding slip circle outcrops in front of the toe of the embankment. If it does not, an additional search is started and the smaller of the obtained minimum factors of safety is returned together with the coordinates and the radius of the corresponding arc.

### Subroutines Required

VARYR(YC,XC,R,XINP,YINP,MINP,MX,MYE,SU,FS,DMIN,YY)

### Remarks

The input data XC and YC are destroyed and replaced by the coordinates of the arc which gives the minimum factor of safety.

The step size is decreased in the subroutine by dividing by 2; it is, thus, possible that the smallest step size used is less than the input value DM.

### 2.25 Subroutine VARYR

#### Purpose

To vary the radii of trial arcs which have the same center coordinates and to compute the associated factors of safety.

#### Usage

CALL VARYR(YC,XC,R,XINP,YINP,MINP,MX,MYE,SU,FS,DMIN,YY)

#### Block Names

SAPOD/IOUTP\*,W\*,H,GLOAD\*,CLOAD\*,NARC\*,NRAD;  
\* parameters marked by an asterisk are not needed in  
this subroutine

#### Description of Parameters

YC        - Y-coordinate of the center of the circular slip  
          surfaces



XC        - corresponding X-coordinate

R        - resulting radius of the arc which gives the minimum  
          factor of safety for the center (XC,YC)

XINP     - X-coordinate of the points defining the embankment  
          contour

YINP     - corresponding Y-coordinates

MX       - number of equally spaced grid points in the  
          horizontal direction

MYE      - number of equally spaced grid points in the  
          vertical direction

SU       - undrained shear strengths at (MX\*MYE) grid points

FS       - resulting factor of safety

DMIN     - minimum step size to be used in the search  
          procedure

YY       - minimum permissible value for YC

H        - thickness of the soft soil layer

NRAD     - number of trial radii to be used at the input  
          center (XC,YC)

#### Method and References

After determination of the maximum and minimum possible radii, RMAX and RMIN, respectively, the factors of safety are computed for NRAD radii  $R = RMAX - I * (RMAX - RMIN) / (NRAD - 1)$ . The minimum value of the so-obtained NRAD factors of safety is returned to the calling program.

#### Subroutines Required

DETFS(XC,YC,R,XINP,YINP,MINP,MX,MYE,SU,FS)

### 3. Input Data

The main program is written in a interactive manner so that the user will be able to input the following data.

1. Name of the input file (length limited to 50 spaces)
2. Name of the output file (length limited to 50 spaces)
3. Number of symbols to be used in the output graph after execution
4. The characters that are used in the output graph after execution

On execution of the program the following messages will appear on the screen one by one and the user should input the corresponding data.

1. Specify the name of the input file
2. Specify the name of the output file
3. Specify the number of symbols to be used (usually 4)
4. Specify the characters - blank, star, grid, symb(I) I=1,  
mmm

After specifying these data, the program will use the data on the specified input file and write the results on the specified output file.

Proposed characters are:

Blank            - a blank space

Star            - \*

Grid            - I

Symb(1) = U    - for avg. degree of consolidation as a percentage  
                 of reference load

Symb(2) = C    - consolidation settlement as a percentage of  
                 that of reference load

Symb(3) = O    - immediate settlement as a percent of that of  
                 reference load

Symb(4) = T    - total settlement as a percent of that of  
                 reference load

(See sample problems for the proper use of these)

This section illustrates the sequence of input data in the main program. A free format style is used. These input data must be given in an input file (the name of the input file is specified by the user).

(a) Input data corresponding to the mesh-generation for the numerical solution, in the compressible layer and type of analysis required.

1. MYE,MHE,ISP,HF,POR,IPOR

MYE            - number of equivally spaced points in the  
                 vertical direction, including the surface

and the bottom of the compressible layer  
in the finite difference mesh in the  
compressible soil  $MYE \leq 12$

MHE - number of points in the horizontal direction  
(mesh points) in the compressible soil  
(MHE  $\leq 40$ )

ISP - identifier where  
    ISP=0 - settlements, the process of  
            consolidation and the stability  
            are analyzed  
    ISP=1 - settlements and the process of  
            consolidation are analyzed. Times  
            of load application are required  
            as input parameters

HF - identifier where  
    HF=0.0 - horizontal flow is neglected in  
            the process of consolidation  
    HF=1.0 - horizontal flow is not neglected  
            in the process of consolidation

POR - ratio horizontal drainage distance divided  
      by  $(XT(IEND)*W)$  in the case of ISP=1, and  
      Set POR=1.0 if this is not known

IPOR - identifier where  
    IPOR=1 - The user provides the value of POR  
    IPOR=0 - the user provides POR=1.0  
            the program will calculate the  
            value of POR

2. JND (add this card only if ISP=0)

JND - number of points in the horizontal  
      direction for which output are required  
      JND  $\leq 10$

3. (JSP(K),K=1,JND) (add this card only if ISP=0)

JSP(K) - indices of the JND points for which  
          output is required. K=1,JND  $\leq 10$ ; the  
          output is for points XE(JSP(K)), where XE  
          are MX equally spaced coordinates between

and including the limits  $AX(1) \cdot W$  and  $AX(NI) \cdot W$ ;  
for example, specification of  $JSP(1)=1$ ,  
 $JSP(JND)=MX$  causes the output of information  
at the limits  $W \cdot AX(1)$  and  $W \cdot AX(NI)$   
respectively.

4. LND

LND - number of weeks to be plotted on the  
time axis of the graphical output

5. MX, NI (add this card only if  $ISP=0$ )

MX - number of equidistant points in the X-direction  
between limits  $AX(I)$  and  $AX(NI)$   
 $MX < 51$  User may chose MX as equal to  
MHE

NI - number of interval limits  $AX(I)$ ;  $NI < 5$

Notes:

$AX(NI) \cdot W$  is the last point (which is considered in the  
analysis) in the horizontal direction from the CL.  $AX(1)=0.0$  is  
the centerline of the embankment.

This horizontal distance between  $AX(1)$  and  $AX(NI)$  is divided  
into NI subdivisions. Each subdivision is further divided into  
MXT points. User may typically use 3-4 subdivisions for each  
interval between  $AX(I) \cdot W$  and  $AX(I+1) \cdot W$ . (Ref. Krizek and Krug-  
man, 1972 for details.)

6. ( $AX(I)=1, NI$ ) (add this card only if  $ISP=0$ )

$AX(I)$  - sub-interval limits as decimal fractions of  
reference value W (select values such  
that a smooth curve along the pore pressure  
vs.  $AX(I) \cdot W$  will give the expected  
shape of the pore pressure distribution)  
(Hint - let contour points of the embankment  
be some of the  $AX(I) \cdot W$ )

7. (MXT(I),I=1,NI-1 (add this card only if ISP=0)

MXT(I) - number of unequivally spaced points XT  
between the consecutive limits AX(I)  
and AX(I+1). I=1, NI-1. Maximum value  
of MXT(I) < 10. Sum of all MXT(I) < 20

8. IEND (add this card only if ISP=1)

IEND - number of points in the horizontal  
direction for which output are  
required

9. (XT(I) I=1,IEND) (add this card only if ISP=1)

XT(I) - X-coordinates of the points at which  
the settlements and the consolidation  
behavior are determined  
Output are printed for points at distance  
XT(I)\*W

(b) This section gives data corresponding to the compressi-  
ble layer under the embankment.

10. H,GLOAD,CLOAD,W,YWM,TGPHI

H - thickness of the compressible layer  
dimension (ft)  
If H=0 the program is terminated

GLOAD - unit weight of the embankment soil  
(pcf)

CLOAD - undrained strength of the embankment  
soil (psf)

W - reference value in the horizontal  
direction (ft)

- YWM - thickness of a drainage blanket placed on the surface of the compressible soil layer (ft)
- TGPHI - tangent of the angle of internal friction of the drainage blanket, if there is one

11. IBCV, LAYER

- IBCV - identifier where  
         IBCV=1 - impeded drainage at Y=H  
         =2 - free drainage at Y=H  
         =3 - no drainage at Y=H
- LAYER - number which indicates the location of a layer interface; e.g. LAYER=KK means that the layer interface is located at a depth below ground surface which is equal to  $Y = \frac{H * (KK - 1)}{(MYE - 1)}$   
         If only one type of soil is to be considered SET LAYER=0  
         4 LE \* LAYER \* LE \* (MYE - 3)

12. HI, RKV (add this card only if IBCV=1)

- HI - thickness of impedance layer
- RKV - ratio of vertical permeabilities  
          $\frac{K(\text{drainage soil})}{K(\text{impedance layer})}$

13. RK, RC, REO, RAV, RCC, ROCL (add this card only if LAYER > 3)

- RK - ratio of vertical permeabilities

	$\frac{K(\text{lower soil})}{K(\text{upper soil})}$
RC	- ratio of (vertical) coeff. of consolidation $c_v$ $\frac{c_v(\text{lower soil})}{c_v(\text{upper soil})}$
ROCL	- ratio of recompression index of lower soil to that of upper soil
REO	- ratio of initial void ratios $\frac{e_o(\text{lower soil})}{e_o(\text{upper soil})}$
RCC	- ratio of virgin compression index $C_c$ $\frac{c_c(\text{lower soil})}{c_c(\text{upper soil})}$
RAV	- ratio of coefficient of compressibility $a_v$ $\frac{a_v(\text{lower soil})}{a_v(\text{upper soil})}$

#### 14. IVAR, IAV, ICV

All these are identifiers where

IVAR=0	- use constant coeff. of consolidation
IVAR=1	- use variable coeff. of consolidation which are obtained either by interpolation between CHIN(I) and CVIN(I) or by varying the coeff. of compressibility and/or the coefficient of permeability (i.e., if ICV > 0)
IAV=0	- use a constant coeff. of compressibility in the settlement computations
IAV=1	- use the compression indices in the settlement computations
ICV	- number of data pairs [PCV(I), CVIN(I)] and [PCH(I), CHIN(I)] through which



Lagrangean/Linear interpolation  
polynomials are passed  
 $0 < ICV < 0$

15. EO, A

EO - initial void ratio of the upper soil  
A - Skempton's pore pressure coefficient (A)

16. AVO (add this card only if IAV=0)

AVO - constant coeff. of compressibility  
to be used in the settlement  
computations; in the case of  
two layers AVO applies to  
the upper layer ( $\text{ft}^2/\text{lb}$ )

17. CC,ROC,GAMMA (add this card only if IAV=1)

CC - virgin compression index (in the case of two  
layers this applies to the upper  
layer)  
ROC - ratio of recompression index to the virgin  
compression index (in the case of two  
layers - upper layer)  
GAMMA - effective unit weight of the subsoil,  
constant over the thickness of the  
compressible layer  
If GAMMA=0, input of MYE effective  
overburden stress at equivalently  
spaced depths must be input (pcf)

18. P(I), PC(I) (add this card only if GAMMA=0) (total of MYE  
cards)

- P(I) - present overburden effective stress at MYE equally spaced depths, including the surface MYE  $\leq$  12 (psf)
- PC(I) - preconsolidation stresses at MYE equally spaced depths, including surface, MYE  $\leq$  12 (psf)

19. CV, CH (add this card only if IVAR=0 and ICV=0)

- CV - constant coeff. of consolidation in the vertical direction (in the case of two layer-upper layer) ( $\text{ft}^2/\text{day}$ )
- CH - constant coeff. of consolidation in the horizontal direction (in the case of two layers-upper layer) ( $\text{ft}^2/\text{day}$ )

20. PCV(I), CVIN(I), PHC(I), CHIN(I) (add this card only if IVAR=1 and ICV>0) (ICV number of cards)

- PCV(I) - effective stresses at which the vertical coeff. of consolidation CVIN(I) are defined ICV  $\leq$  10 (psf)
- PCH(I) - effective stresses at which the horizontal coeff. of consolidation CHIN(I) are defined (psf) ICV  $\leq$  10
- CVIN(I) - variable coefficients of consolidation in the vertical direction (interpolation is done in subroutine coef) ( $\text{ft}^2/\text{day}$ ) ICV  $\leq$  10
- CHIN(I) - variable coeff. of consolidation in the horizontal direction (interpolation is done in subroutine coef) ( $\text{ft}^2/\text{day}$ ) (ICV  $\leq$  10)

21. KVO, KHO (add this card only if IVAR=1 and ICV=0)

KVO - initial coeff. of permeability in  
the horizontal direction  
KHO - initial coeff. of permeability in  
the vertical direction  
(ft/day)

22. ISAT,IK (add this card only if IVAR=1 and ICV > 0)

These are identifiers where

ISAT=0 - complete saturation  
=1 - partial saturation; requires  
Skempton's pore pressure  
parameter B < 1.0  
IK=0 - constant coefficient of permeability  
=1 - horizontal and vertical permeabilities  
are variables; void ratio vs. the  
logarithm of the coeff. of  
permeability is a straight line

23. S,PU,HC,B (add this card only if IVAR=1,ICV > 0 and ISAT=1)

S - degree of saturation to be input as a  
decimal fraction < 1.0  
PU - initial pore gas pressure, if PU is  
not defined during input, it is set  
equal to the sum of the atmosphere  
pressure plus one half the thickness  
of the compressible layer times  
the unit weight of water (psf)  
HC - Henry's constant of gas solubility,  
HC=0.020 for atmospheric air,  
HC=0.029 for methane, HC=2.84  
for hydrogen sulfide (at 68°F)  
B - Skempton's pore pressure coefficient (B)

24. SKV,SKH (add this card only if IVAR=1,ICV>0,IK=1)

SKV - slope of the void ratio vs. logarithm of vertical coeff. of permeability

SKH - slope of the void ratio vs. logarithm of horizontal coeff. of permeability

25. NC (add this card only if ISP=0)

NC - number of initial undrained shear strengths,  $CO(I)$ , and  $(c/\bar{p})$ -ratios,  $CP(I)$ ;  
NC  $\leq$  MYE  $\leq$  12

26. Y UA(I), UB(I) (add this card only if ISP=0) (total of NC cards)

Y - vertical distance below the ground surface at which the initial shear strengths are given (positive downwards) (ft)

UA(I) - initial undrained shear strength  $CO(I)$  at depth Y (psf)

UB(I) -  $(c/\bar{p})$ -ratio at depth Y

\* At this point the program will write the data on the OUTPUTFILE.

(c) Following data corresponds to the REFERENCE LOAD.

27. MINP, NS

MINP - the number of points where the coordinates of the embankment will be given. This defines the contour of the embankment (MINP  $\leq$  20)

NS - number of load strips to approximate the actual embankment load (NS  $\leq$  20)

28. XINP(I), YINP(I) (total of MINP cards)

XINP(I) - X-coordinates of the points defining  
the embankment contour (ft)  
(MINP ≤ 20)

YINP(I) - Y-coordinates of the points defining  
the embankment contour (ft)  
(MINP ≤ 20)

(d) Following data corresponds to the load application  
(i.e. each step of load to the embankment).

29. NL,(IDEN(I),I=1,NL)

NL - number of load strips (NL ≤ 6)

IDEN(I) - identifier corresponding to the Ith load strip; where  
IDEN(I) < 0 - the excess pore pressure due to  
the first load step are equal to  
the input residual pore pressure  
IDEN(I) = 0 - the excess pore water pressure due  
to the Ith load are computed by  
means of subroutine PORE  
IDEN(I) = 1 - the excess pore pressure due to the  
Ith load are set equal to those  
computed for the reference load.  
Note, that this requires that  
Skempton's coefficients A and B  
are identical in both cases  
IDEN(I) < 0 - allows the check of an existing  
installation for which the excess  
pore pressures just after load  
application are known from field  
measurements

30. (TL(I),I=1,NL) (add this card only if ISP=1)

TL(I) - times of load application (i.e. each  
step of load) in case where ISP=1  
NL ≤ 6 (days)

31. FSI,SPEC(1),SPECU(1),TA,DMAX,DMIN,XC,YC,ZZ (add this card  
only if ISP=0)

FSI - factor of safety required at the time of  
application of the first load

SPECS(1) - specified fraction of the consolidation  
settlement due to the reference load.  
This settlement must have occurred before  
a new load is applied.

SPECU(1) - when the non-dissipated average pore  
pressures become less than 5% of the  
total average pore pressure just after the  
application of the last load at IEND\*SPECU  
points XT the subsequent loads are disregarded  
SPEC is a decimal fraction. IEND is the  
total number of points in the X-direction  
created by the program (see Sec. 2.1)

TA - available construction time. This is the  
time at which the final load must have  
been applied (days)

DMAX - maximum step size to be used in the  
variation of XC and YC in the search  
procedure for the minimum factor of  
safety (ft)

DMIN - minimum step size to be used in the  
variation of XC and YC in the search  
procedure for the minimum factor of  
safety (ft)

XC - X-coordinate of the center of the first  
trial arc, If XC=0 is input, the  
program selects a starting value (ft)

YC - Y-coordinate of the center of the first  
trial arc, IF YC=0 is input, the  
program selects a starting value (ft)  
(Note - positive upward)

32. NARC,NRAD (add this card only if ISP=0)

NARC - one-half the number of subarcs within the  
subsoil to be used in subroutine DETFS;  
NARC > 1

NRAD - number of trial arcs to be used with each  
trial center (XC,YC) in the stability  
analysis; NRAD > 1

33. MINP,NS,IAB (gives data corresponding to the first load)

MINP - same as defined earlier - corresponding to  
the first load

NS - same as defined earlier - corresponding to  
the first load

IAB - identifier where  
IAB=0 - Skempton's pore pressure coefficients  
A and B as defined for the last load  
are also used to compute the pore  
pressures due to the load addition  
IAB=1 - redefine A and B (i.e. assign new  
values for A and B)

34. XINP(I),YINP(I) (total of MINP cards)

XINP(I) - as defined earlier - corresponding to the first load

YINP(I) - as defined earlier - corresponding to the first load

35. A,B (add this card only if IBA=1)

A,B - corresponding Skempton's pore pressure  
parameters (new)

At this point of the program, if satisfactory FS is not reached, within the available construction time, for the first load the program is terminated (i.e., no loads can be added to the existing embankment). Note - this is for ISP=0

(e) The following data refers to the residual pore pressures under the embankment.

36. IRP

IRP - identifier where  
IRP=0 - no residual pore pressures are input  
IRP=1 - residual pore pressure at points  
(W\*XT, H\*YE) are input columnwise  
IRP=2 - residual pore pressure at arbitrary  
points are input

37. (UC(I), I=1, ISUM) (add this card only if IRP=1)

UC(I) - residual pore pressures under the embankment  
at points (WcodtXT, H\*YE) are input columnwise  
(psf)

38. X, Y, UA(I), COUNT (add this card only if IRP=2) (number of cards depends on number of arbitrary pore pressures to be given)

X - the X-coordinate at which residual pore pressure  
UA(I) is specified

Y - the Y-coordinate at which residual pore pressure  
UA(I) is specified

COUNT - identifier where  
COUNT=0.0 - in all the cards except the last card  
COUNT=1.0 - the last data card on residual pore  
pressure

At this point of the program, the internal file unit 1 will be rewinded to initiate the recording of the output data. The program calculates the required parameters corresponding to the first load.



\* Steps in this section should specify second and following loads for a total of (NL-1) lifts with proper values corresponding to each step of load, i.e. total of NL load applications NL ≤ 6 are allowed.

(f) The following data corresponds to the second and following loads. [This data should cover (NL-1) loading steps.]

39. MINP,NS,IAB (gives data corresponding to the 2nd load step)

MINP  
NS as defined earlier - corresponding to the 2nd  
IAB load step

40. XINP(I),YINP(I) (gives the contour of the embankment for the 2nd or following load steps) (total number of cards = MINP)

XINP(I) - as defined earlier - corresponding to the  
YINP(I) 2nd or following load step

41. A,B (add this card only if IAB=1)

A - pore pressure parameters  
B

42. FSI,SPECS(LL),SPECU(LL),TMIN,XC,YC,ZZ (add this card only if ISP=0)

FSI - specified required factor of safety for the 2nd  
load step  
  
SPECS(LL) - specified fraction of the consolidation  
settlement due to reference load that must

have occurred before the addition of the next load step

SPECU(LL) - if an average degree of consolidation of 95% due to the LIFT-TH load is obtained at SPECU(LIFT)\*IEND points XT without a sufficient factor of safety for the present load (i.e. LLth load) the LIFTth load is taken to be the last load and NL is set at NL=LIFT (i.e. the present load will not be added to the embankment)  
SPECU is input as a decimal fraction (see Sec. 2.1)

TMIN - time which must have passed after a load application before the first stability is made to determine whether the next load can be applied. (This saves unnecessary computer time in calculating FS before sufficient pore pressure is dissipated.)

XC

YC

ZZ

- as defined previously - corresponding to the LLth load

Note: The program can handle analysis of multiple embankments in a single run.

This is done by adding the card No. 10 at the end of the cards for the previous embankment but with replacing H = 99.

This makes the program to goto the beginning of cards. For second or following embankments data cards should be repeated from 1-42 as in the case of first embankment.

To terminate the program at the end of analysis of  $n^{th}$  embankment, simply add the card #10 with H = 0 at the end of data cards for the  $n^{th}$  embankment.

#### 4. Sample Problems

Two sample problems have been prepared to show some of the features of the computer programs. In the first problem, only a settlement analysis for a specified load history is required, whereas the second problem simulates actual design conditions

using soil data and cross-section from an unpublished report by the STATE OF ILLINOIS, DIVISION OF HIGHWAYS (1967).

#### 4.1 Sample Problem for Settlement Analysis (Sample Problem #1)

In this first problem the load, which includes a surcharge of 5 feet, is applied at time  $TL(1)=60$  days, and the surcharge is removed at time  $TL(2)=160$  days. The geometry is given in Figure 4.1, and the soil parameters, which are assumed to vary during consolidation, are compiled in Table 4.1 and in Figure 4.2. Output of pore water pressures is required at specified points under the embankment. The input sequence for the soil parameters, the geometry, and the load characteristics follows the list of data cards given in Section 3 for program "Modified SAND" with  $ISP=1$ , and the contents of the data cards are listed in Table 4.2 in Appendix A.

The computer output has been abridged, where it was repetitive in nature, and is reproduced in Figure 4.3 in Appendix A.

#### 4.2 Sample Design Problem (Sample Problem #2)

The geometry for this problem is depicted in Figure 4.4 together with a summary of the soil conditions deduced from the boring log shown in Figure 4.5 and the consolidation test data of Figure 4.6. To account for the smaller initial void ratio and larger coefficients of consolidation near the ground surface, it was decided to introduce a layer interface at a depth of  $(H-H')=5.2$  feet, corresponding to  $LAYER=3$ .

The design must satisfy the following requirements: (1) No settlements due to primary consolidation must occur after surcharge removal; in addition, some settlements due to secondary compression should be eliminated; (2) the construction time is not to exceed 12 months; and (3) the factor of safety against instability of the embankment-subsoil system must be equal to or greater than 1.15 during construction and 1.25 under the final load.

The input sequence for the soil parameters, the geometry, and the load characteristics follows the input data in Section 3 for program Modified SAND with  $ISP=0$ , and the contents of the data cards are listed in Table 4.3 (Appendix A). The final output includes average degrees of consolidation for a point at the center of the embankment and another point close to the embankment toe, and is reproduced in Figure 4.7 (Appendix A).

#### 4.3 Summary and Conclusions

The objectives of this study were (a) to elucidate the practical and theoretical bases for using the controlled rate of construction technique to design a highway embankment underlain by soft ground, and (b) to synthesize presently available procedures in a comprehensive computer program in which special attention is given to the horizontal and vertical drainage, without sand drain installations. An existing program SAND which considers sand drains has been modified for this purpose.

To facilitate the mathematical treatment, the overall problem was conveniently divided into four parts, which deal with (a) the initial increase in excess pore water pressures caused by an increase of the vertical load on the surface of the compressible layer, (b) the process whereby these pore water pressures are dissipated with time, (c) the associated settlements, and (d) the stability of the embankment-foundation system.

Based on the effective stress principle, the stress increases associated with primary consolidation are taken to be equal to the dissipated pore water pressures. The latter are computed by means of Skempton's pore pressure coefficients  $A$  and  $B$  and a solution for the total stresses due to a symmetric vertical load acting on a linearly elastic layer of finite thickness, which, in turn, is underlain by a rough rigid substratum. The dissipation of excess pore water pressures is evaluated by use of a consolidation theory which accounts for horizontal and vertical drainage conditions, anisotropic permeability, time-dependent variations of the soil parameters, and partial saturation. As a result of the increases in effective stresses due to the dissipation of pore water pressures, the strength of the subsoil increases, and this is considered in a stability analysis in terms of total stresses by use of the  $c/\bar{p}$ -ratio.

It is economically possible to establish a number of design charts, which include (a) excess pore pressure distribution curves, (b) consolidation-time curves, (c) stability charts, (d) graphs of maximum embankment height versus thickness of the compressible layer, and (e) relationships for equivalent uniform strength after complete consolidation versus thickness of the subsoil. However, this is beyond the scope of this report.

Since the computational technique used in the "Modified Sand" remains the same as in the original program and the following remarks are valid.

A. With regard to the computation of the initial excess pore water pressure distribution, the following conclusions can be drawn:

1. The form of the stress equations requires the numerical integration of oscillating integrands, and convergence of the extended Simpson's rule or Filon's formulae with interval halving depends on the geometry of the problem. Poorest convergence was obtained in cases of heavily oscillating integrands when the ratio of the load width to the thickness of the compressible layer was large.
2. When the pore pressure coefficient  $B$  is held constant and equal to unity, the influence of the pore pressure coefficient  $A$  increases as the thickness of the compressible layer increases, and the average pore water pressures are larger and extend farther in the horizontal direction when  $A$  is larger.

3. As the compressible layer becomes thinner relative to the load width, closer agreement is obtained between the applied vertical load and the resulting average pore pressure distribution.
4. The influence of shear stresses causes some concentration of average pore water pressures near the edges of the load.

B. With regard to the computation of primary consolidation settlements, direct proportionality between the average degree of consolidation and the resulting settlement will occur only when constant coefficients of consolidation and a constant coefficient of compressibility are used.

C. With regard to the stability analyses, the following conclusions can be drawn from a critical comparison of the charts in the report (Krizek and Krugman, 1972):

1. Depending on the geometry of the embankment and the soil parameters of the embankment and the subsoil, the assumption of a circular slip surface will give reliable factors of safety only for sufficiently large subsoil thicknesses.
2. The stabilizing influence of flattening the embankment slope decreases as the thickness of the subsoil increases.

3. The slip circle resulting in a minimum factor of safety generally tends to penetrate the soft subsoil as deep as possible.
4. The factor of safety is not proportional to the height of the embankment, but, given identical soil parameters, it depends on the ratio of the embankment height and the thickness of the compressible layer.

#### Reference

Krizek, R. J. and Krugman, P. K. (1972) "Placement Rates for Highway Embankments", Vol. 1-4, Final Report 1972, Proj. IHR-602, Northwestern University, The Technical Institute, Dept. of Civil Engineering, Evanston, Illinois 60201.



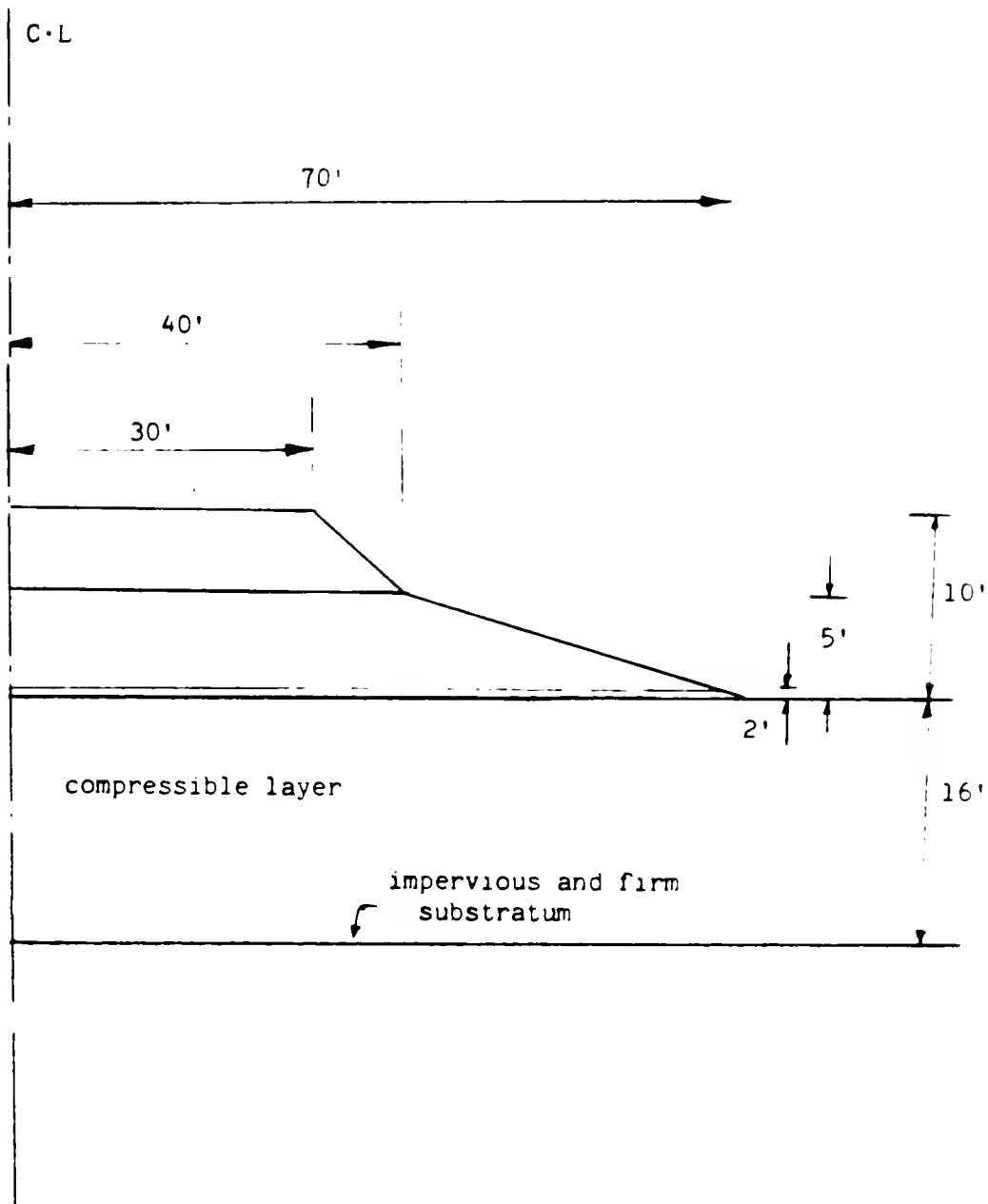


Fig. 4.1 Contour of the Embankment Configuration  
for the Sample Problem 1

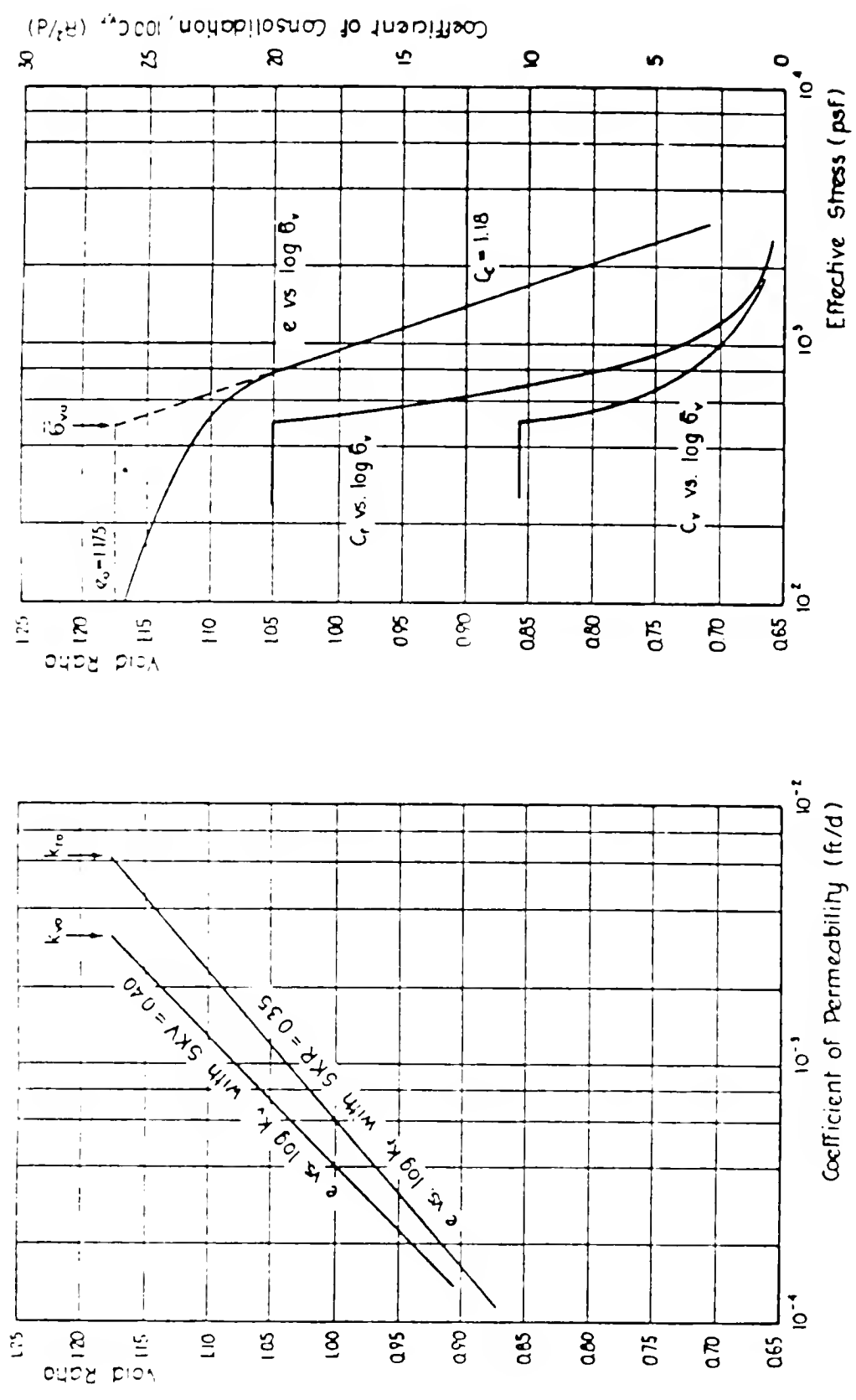


Figure 4.2 Soil Characteristics of a Sample from Depth of 8 ft below Ground

Table 4.1 Soil Data for the First Sample Problem

Soil Parameter	Embankment	Subsoil
Unit weight (pcf)	125	58.8
Initial coefficient of permeability (feet/day)		$K_{HO} = 6.26 \times 10^{-3}$ $K_{VO} = 3.08 \times 10^{-3}$
Slope of the void ratio versus log coefficient of permeability curve		$SKH = 0.35$ $SKV = 0.40$
Initial void ratio, $e_o$		1.175
Compression index, $C_c$		1.18
Skempton's pore pressure coefficients		$A = 0.5$ $B = 0.95$
Degree of saturation, $S$		$S = 0.98$
Henry's coefficient of gas solubility, $HC$		0.02

11,40,10,1,1.000,1.00,0  
40  
10  
0.0,.1,.2,.3,.4,.5,.7,.9,1.5,1.600  
16.0,125.0,1000.,100.,2.0,0.0  
3,0  
1,1,0  
1.175,0.500  
1.18,1.0,58.80  
.00308,0.00625  
1,1  
0.98,0.0,0.2,0.95  
0.4,0.35  
3,5  
0.0,5.0  
40.0,5.0  
70.0,0.0  
2,0,1  
60.0,160.0  
4,10,0  
0.0,10.  
30.0,10.0  
40.0,5.0  
70.0,0.0  
2  
35.0,4.0,75.0,0.0  
35.0,15.0,75.0,0.0  
105.0,8.5,25.0,1.0  
3,5,0  
0.0,5.0  
40.0,5.0  
70.0,0.0  
0.0,0.0,0.0,0.0,0.0,0.0

Table 4.2 Data Cards for Sample Problem 1

```

*****
*
*      CONSOLIDATION PROBLEM      *
*
*      STEP LOADING & SURCHARGE  *
*
*****

```

Abridged output for Sample Problem 1

THE PORE WATER PRESSURES ARE COMPUTED AT

YE/H	0.000	0.100	0.200	0.300	0.400
YE/H	0.500	0.600	0.700	0.800	0.900
YE/H	1.000				
XT/W	0.000	0.100	0.200	0.300	0.400
XT/W	0.500	0.700	0.900	1.500	1.600

THE SUBSOIL IS DESCRIBED BY THE FOLLOWING PARAMETERS  
WHICH ARE GIVEN FOR THE UPPER LAYER  
IN CASE OF STRATIFICATION

TOTAL THICKNESS H= 16.000 FEET  
reference for X-COORD W = 100.000 FEET

SKEMPTON PORE PRESSURE COEFFICIENTS ARE  
A= 0.50 AND B= 0.95

DEGREE OF SATURATION IS S= 0.980  
HENRY'S CONSTANT OF GAS SOLUBILITY HC = 0.200  
INITL PORE GAS PRESSURE IS PU= 0.2616E+04 PSF

INITIAL VOID RATIO = 1.175

THE COMPRESSION INDEX IS = 0.1180E+01  
RECOMPRESSION INDEX/CC ROC= 1.000  
INITIAL EFFECTIVE P AND PRECOMPRESSION  
STRESSES PC AS USED IN THE COMPUTATIONS  
Y IN FT P IN PSF PC IN PSF

0.000	94.08	94.08
1.600	94.08	94.08
3.200	188.16	188.16
4.800	282.24	282.24
6.400	376.32	376.32
8.000	470.40	470.40
9.600	564.48	564.48
11.200	658.56	658.56
12.800	752.64	752.64
14.400	846.72	846.72
16.000	940.80	940.80

NOTE -P(1) AND PC(1) MAY HAVE BEEN CHANGED  
as compared to input values to avoid over flow

THE INITIAL PERMEABILITIES ARE INVERTICAL DIRN. KVO= 0.3080E-02 FT/DAY  
HORIZONTAL DIRN KHO= 0.6250E-02 FT/DAY  
THE SLOPES OF THE E Vs LOG(K)-CURVES ARE  
IN VERTICAL DIRN, SKV= 0.400  
IN HORI. DIRN, SKH= 0.350

THE DRAINAGE CONDITIONS ARE

NO DRAINAGE AT THE BOTTOM

0

REFERENCE LOAD

\*\*\*\*\*

SKEMPTON PORE PRESSURE COEFFICIENTS ARE

A= 0.50 AND B= 0.95

THE LOAD CHARACTERISTICS ARE GIVEN BY

THE UNIT WEIGHT GLOAD= 125.00 PCF

THE COHESION , CLOAD= 1000.00 PSF

THICKNESS OF THE DRAINAGE BLANKET YWM= 2.00 FT

THE TANGENT OF THE ANGLE OF INTERNAL

FRICTION TGPHI= 0.0000

MINP= 3 COOR POINTS XINP/YINP

0.00 FEET 5.00 FEET

40.00 FEET 5.00 FEET

70.00 FEET 0.00 FEET

THE ACTUAL LOAD IS APPROXIMATED BY 5 LOADS

OF EQ INTENSITY WHICH EXTEND FROM X=0 TO ALPHA(I)

IF ALPHA(I) IS NEGATIVE, THIS LOAD IS SUBTRACTED

ALPHA( 1) = 67.000 FEET

ALPHA( 2) = 61.000 FEET

ALPHA( 3) = 55.000 FEET

ALPHA( 4) = 49.000 FEET

ALPHA( 5) = 43.000 FEET

THE AVERAGE PORE PRESSURES, UAVER(I)

THE CONSOLIDATION SETTLEMENTS, SETRC(I) AND

THE TOTAL SETTLEMENTS, SETRT(I), AT XT(I) ARE

XT FEET	UAVER (PSF)	SETRC FT.	SETRT FT
0.00	585.99	3.781	3.896
10.00	585.24	3.777	3.892
20.00	581.91	3.761	3.876
30.00	573.86	3.728	3.842
40.00	540.09	3.604	3.715
50.00	401.90	2.975	3.074
70.00	112.84	1.131	1.180
90.00	37.77	0.515	0.539
150.00	2.43	0.037	0.039
160.00	1.52	0.023	0.024

THE NUMBER OF LIFTS IS NL= 2

SINCE ISP=1 TIMES OF LOAD APPLICATION

ARE INPUT TO BE

TL( 1)= 60. DAYS

TL( 2)= 160. DAYS

0

RESIDUAL PORE PRESSURES ARE IN PUT AS

X (FEET)	Y (FEET)	UC (PSF)
35.000	4.000	75.000
35.000	15.000	75.000
105.000	8.500	25.000

0

LOAD NO 1 APPLIED AT TL= 60.DAYS

\*\*\*\*\*

SKEMPTON PORE PRESSURE COEFFICIENTS ARE  
A= 0.50 AND B= 0.95

THE LOAD CHARACTERISTICS ARE GIVEN BY  
THE UNIT WEIGHT GLOAD= 125.00 PCF  
THE COHESION , CLOAD= 1000.00 PSF  
THICKNESS OF THE DRAINAGE BLANKET YWM= 2.00 FT  
THE TANGENT OF THE ANGLE OF INTERNAL  
FRICTION TGPHI= 0.0000  
MINP= 4 COOR POINTS XINP/YINP  
0.00 FEET 10.00 FEET  
30.00 FEET 10.00 FEET  
40.00 FEET 5.00 FEET  
70.00 FEET 0.00 FEET

THE ACTUAL LOAD IS APPROXIMATED BY 10 LOADS  
OF EQ INTENSITY WHICH EXTEND FROM X=0 TO ALPHA(I)  
IF ALPHA(I) IS NEGATIVE, THIS LOAD IS SUBTRACTED

ALPHA( 1) = 67.000 FEET  
ALPHA( 2) = 61.000 FEET  
ALPHA( 3) = 55.000 FEET  
ALPHA( 4) = 49.000 FEET  
ALPHA( 5) = 43.000 FEET  
ALPHA( 6) = 39.000 FEET  
ALPHA( 7) = 37.000 FEET  
ALPHA( 8) = 35.000 FEET  
ALPHA( 9) = 33.000 FEET  
ALPHA(10) = 31.000 FEET

T= 0. DAYS X/W 0.000 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
1217.070  
1220.074  
1223.127  
1226.202  
1229.288  
1232.371  
1235.432  
1238.484  
1241.515  
1244.547

T= 0. DAYS X/W 0.100 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
1203.986  
1207.619  
1211.390

1215.356  
1219.585  
1224.196  
1229.339  
1235.257  
1242.284  
1250.778

T= 0. DAYS X/W 0.200 PORE PRESSURES IN PSF DUE TO VERT + HORI FLO

0.000  
1184.936  
1185.586  
1186.735  
1188.883  
1192.537  
1198.191  
1206.311  
1217.356  
1231.762  
1249.895

T= 0. DAYS X/W 0.300 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
1137.844  
1106.615  
1088.493  
1078.696  
1075.409  
1077.865  
1085.907  
1099.824  
1120.355  
1148.747

T= 0. DAYS X/W 0.400 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW



0.000  
701.713  
735.499  
758.469  
775.872  
790.112  
802.631  
814.362  
825.931  
837.748  
850.041

= 0. DAYS X/W 0.500 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
510.896  
519.972  
527.333  
534.959  
542.353  
549.100  
554.951  
559.745  
563.326  
565.497

= 0. DAYS X/W 0.700 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
184.606  
198.226  
205.020  
207.824  
207.960  
206.043  
202.389  
197.170  
190.481  
182.376

T= 0. DAYS X/W 0.900 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
99.416  
96.627  
93.800  
90.903  
87.904  
84.783  
81.525  
78.128  
74.598  
70.955

T= 0. DAYS X/W 1.500 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
-3.144  
-3.296  
-3.459  
-3.630  
-3.810  
-3.996  
-4.188  
-4.386  
-4.588  
-4.793

T= 0. DAYS X/W 1.600 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
-11.767  
-11.867  
-11.969  
-12.077  
-12.190  
-12.308  
-12.430  
-12.554  
-12.681  
-12.811

T= 7. DAYS X/W 0.000 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
1005.060  
1198.883  
1221.441  
1225.869  
1229.022  
1232.104  
1235.166  
1238.208  
1241.145  
1243.217

T= 7. DAYS X/W 0.100 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
994.349  
1186.681  
1209.759  
1215.080  
1219.404  
1224.050  
1229.243  
1235.208  
1242.004  
1247.581

T= 7. DAYS X/W 0.200 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
977.065  
1164.192  
1184.553  
1188.139  
1191.965  
1197.717  
1205.925  
1217.008  
1230.826  
1242.611

T= 7. DAYS X/W 0.300 PORE PRESSURES IN PSF DUE TO VERT + HORI FLO

0.000  
927.833  
1084.815  
1085.476  
1076.676  
1073.297  
1075.710  
1083.785  
1097.741  
1117.368  
1135.339

T= 7. DAYS X/W 0.400 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
577.542  
721.089  
757.299  
776.237  
790.899  
803.662  
815.556  
827.204  
838.624  
846.717

T= 7. DAYS X/W 0.500 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
414.049  
509.569  
527.355  
535.724  
543.083  
549.781  
555.599  
560.358  
563.843  
565.502

T= 7. DAYS X/W 0.700 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
150.603  
194.164  
205.344  
208.848  
209.181  
207.338  
203.703  
198.499  
192.169  
187.244

T= 7. DAYS X/W 0.900 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
78.568  
94.598  
94.130  
91.414  
88.405  
85.261  
81.984  
78.583  
75.209  
72.924

T= 7. DAYS X/W 1.500 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
-1.739  
-2.227  
-2.388  
-2.511  
-2.635  
-2.764  
-2.896  
-3.032  
-3.165  
-3.253

T= 7. DAYS X/W 1.600 PORE PRESSURES IN PSF DUE TO VERT + HORI FLO

0.000  
-9.327  
-11.585  
-11.964  
-12.096  
-12.211  
-12.329  
-12.450  
-12.574  
-12.695  
-12.776

T= 49. DAYS X/W 0.000 PORE PRESSURES IN PSF DUE TO VERT + HORI FLO

0.000  
623.692  
1002.445  
1160.141  
1210.504  
1224.987  
1230.310  
1233.690  
1236.544  
1238.756  
1239.663

T= 49. DAYS X/W 0.100 PORE PRESSURES IN PSF DUE TO VERT + HORI FLO

0.000  
616.674  
992.046  
1149.208  
1200.274  
1216.000  
1223.013  
1228.602  
1234.115  
1238.871  
1240.950

T= 49. DAYS X/W 0.200 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
602.520  
968.304  
1120.361  
1169.126  
1184.414  
1192.669  
1201.194  
1211.012  
1220.169  
1224.311

T= 49. DAYS X/W 0.300 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
555.691  
884.480  
1011.757  
1045.370  
1052.045  
1056.211  
1064.053  
1075.741  
1087.899  
1093.667

T= 49. DAYS X/W 0.400 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
346.340  
585.257  
709.914  
766.264  
793.195  
809.690  
822.583  
833.496  
841.602  
844.765

T= 49. DAYS X/W 0.500 PORE PRESSURES IN PSF DUE TO VERT + HORI FLO

0.000  
235.913  
401.698  
489.368  
528.088  
545.007  
554.048  
560.212  
564.747  
567.677  
568.711

T= 49. DAYS X/W 0.700 PORE PRESSURES IN PSF DUE TO VERT + HORI FLO

0.000  
86.603  
152.094  
190.724  
208.935  
215.348  
215.791  
213.319  
209.699  
206.487  
205.181

T= 49. DAYS X/W 0.900 PORE PRESSURES IN PSF DUE TO VERT + HORI FLO

0.000  
40.089  
69.237  
84.641  
89.974  
89.981  
87.780  
84.901  
82.121  
80.055  
79.277



T= 49. DAYS X/W 1.500 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
-1.436  
-2.565  
-3.302  
-3.748  
-4.039  
-4.265  
-4.463  
-4.633  
-4.755  
-4.800

T= 56. DAYS X/W 0.000 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
594.797  
975.207  
1146.130  
1205.399  
1223.418  
1229.753  
1233.346  
1236.194  
1238.329  
1239.177

T= 56. DAYS X/W 0.100 PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW

0.000  
588.056  
965.000  
1135.251  
1195.173  
1214.436  
1222.473  
1228.264  
1233.697  
1238.223  
1240.133

T= 56. DAYS X/W 0.200 PORE PRESSURES IN PSF DUE TO VERT + HORI FL

0.000  
574.192  
941.276  
1106.020  
1163.418  
1182.176  
1191.437  
1200.108  
1209.678  
1218.309  
1222.076

T= 56. DAYS X/W 0.300 PORE PRESSURES IN PSF DUE TO VERT + HORI FL

0.000  
528.166  
857.962  
997.125  
1038.742  
1048.545  
1053.544  
1061.405  
1072.650  
1083.974  
1089.156

Reached end of file

1  
0

THE CONSOL. PROCESS  
\*\*\*\*\*

THE FOLLOWING INFORMATION IS OUT PUT  
 UAVE(X(1)),UAVE(X(2)),.....,  
 = AVER DEGREES OF CONSOL. WITH RESPECT TP REF. LOAD  
 SETC(X(1)),SETC(X(2)),.....,  
 = CONSOL. SETTLEMENTS  
 SETI(X(1)),SETI(X(2)),.....,  
 = IMMEDIATE SETTLEMENTS  
 SETT(X(1)),SETT(X(2)),.....,  
 = CONSOLI. + IMMEDIATE SETTLEMENTS  
 LAST TWO LINE ARE ONLY OUT PUT  
 IF SOIL IS PARTIALLY SATURATED (B.NE.1.)  
 THE POINTS X(1) IN FEET ARE AS FOLLOWS

0.000 10.000 20.000 30.000 40.000 50.000 60.000 70.000 80.000 90.000 100.000 110.000 120.000

T= 60.  
 DAYS IS THE TIME OF LOAD APPLICATION

T= 60. DAYS

0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.141	0.141	0.141	0.138	0.124	0.107	0.059	0.030	0.003	0.002
0.141	0.141	0.141	0.138	0.124	0.107	0.059	0.030	0.003	0.002

T= 67. DAYS

0.154	0.153	0.153	0.159	0.090	0.087	0.081	0.156	-0.545	-0.477
1.002	0.997	0.996	1.010	0.746	0.629	0.286	0.196	0.000	0.000
0.141	0.141	0.141	0.138	0.124	0.107	0.059	0.030	0.003	0.002
1.143	1.138	1.137	1.147	0.870	0.736	0.345	0.226	0.003	0.002

T= 74. DAYS

0.185	0.183	0.185	0.196	0.110	0.108	0.098	0.199	-1.572	-0.383
1.204	1.197	1.201	1.236	0.919	0.785	0.370	0.254	0.000	0.002
0.141	0.141	0.141	0.138	0.124	0.107	0.059	0.030	0.003	0.002
1.345	1.338	1.342	1.373	1.043	0.892	0.429	0.284	0.003	0.004

T= 130. DAYS

0.321	0.319	0.329	0.361	0.199	0.198	0.168	0.372	2.614	-0.956
1.866	1.857	1.890	1.983	1.459	1.251	0.627	0.430	0.050	0.002
0.141	0.141	0.141	0.138	0.124	0.107	0.059	0.030	0.003	0.002
1.007	1.998	2.031	2.121	1.583	1.359	0.686	0.460	0.053	0.004



[illegible][illegible]

4.3(c)

[illegible]

O		U		C	T					*						
O			U			C	T			*						
O				U			C	T		*						
O					U			C	T	*						
O						U			C	T	*					
O							U			C	T	*				
O								U			C	T	*			
O									U			C	T	*		
O										U			C	T	*	
O											U			C	T	*



0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5

[illegible]

```

AVE DEGREE OF CONSOL. AND SETTLEMENT
CURVES FOR POINT X=      90.00FEET FROM CENTER LINE
INTERVAL BETWEEN 2 GRID LINES.EQ.10%
ABSCISSA NUMBERS GIVE THE TIME IN WKS
THE TOTAL SETTL DUE TO REFERENCE LOAD IS= 0.539E+00FT
U -CUREV= AVE. DEGREE OF CONSOL.
RELATIVE TO THE PORE PRESS DUE TO REF LOAD
C -CURVE=CONSOL. SETTL. IN % OF REF. SETTLEMENT
O -CURVE=IMMEDIATE SETTLEMENTS IN % OF
THE REFERENCE SETTLEMENTS
T -CURVE=TOTAL SETTLEMENTS IN % OF
THE REFERENCE SETTLEMENT

```

0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

[illegible]





Route FAI 255, Section 82-8,  
St. Clair County, Illinois  
Station 267+00

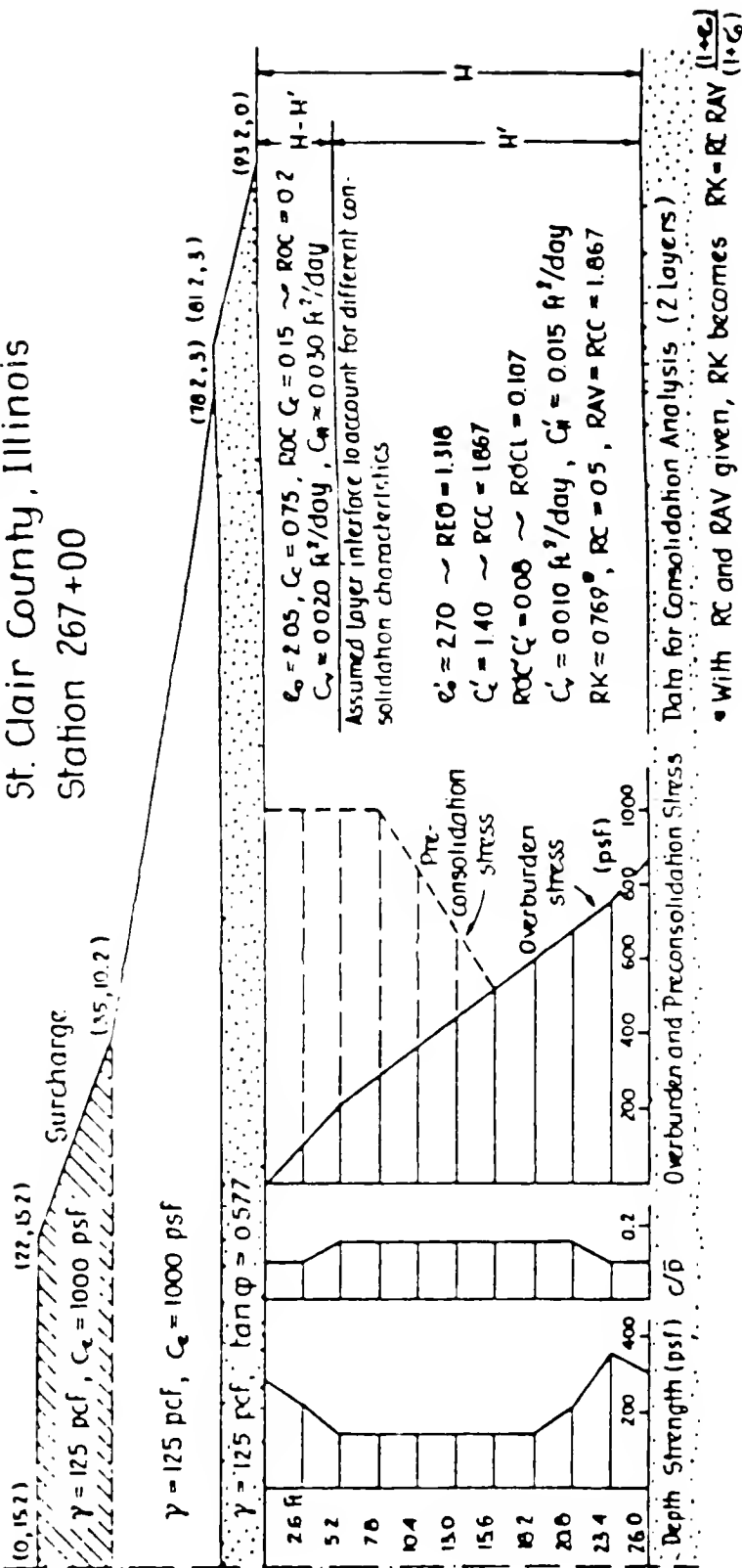


Figure 4.4 Cross-Section and Idealized Soil Condition of the Second Sample Problem

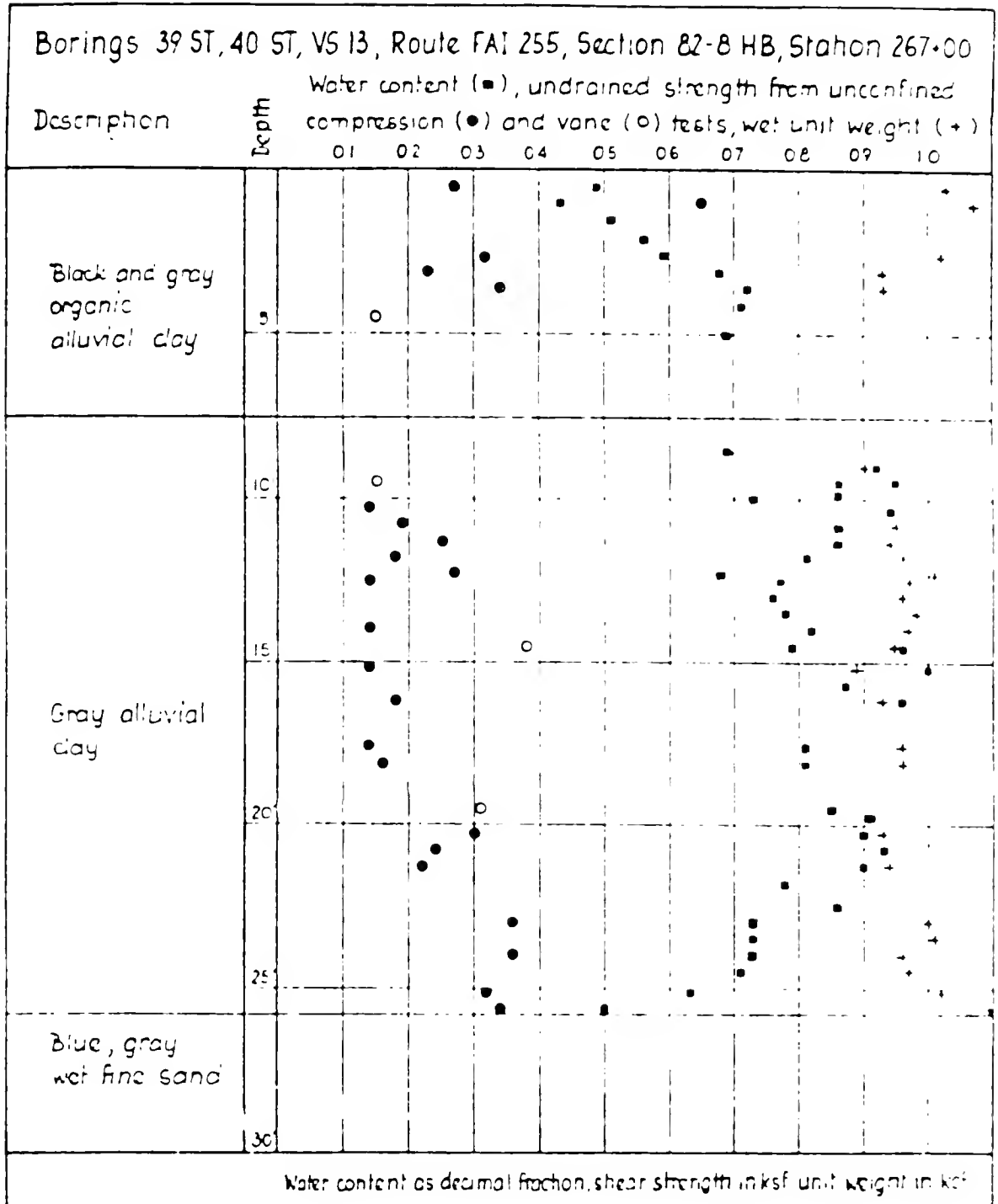


Figure 4.6 Boring Log

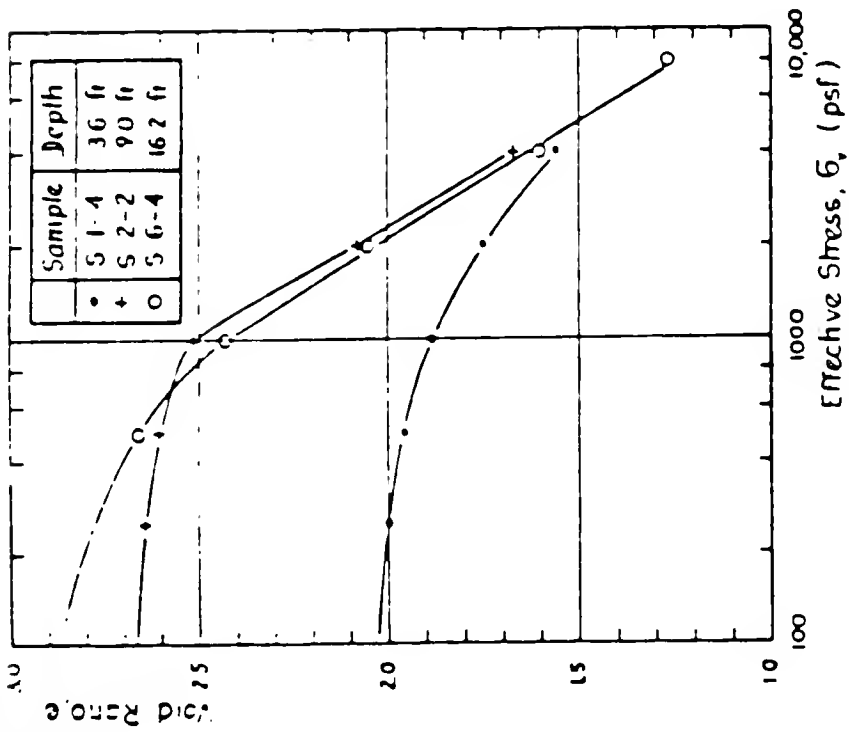
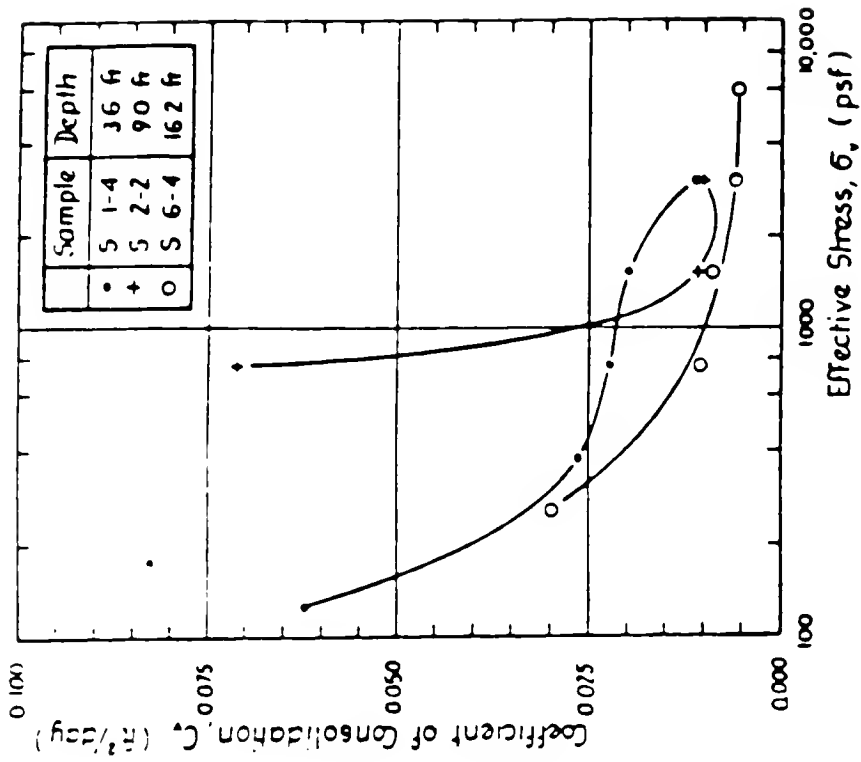


Figure 4.6 Consolidation Test Data

11,30,31,0,1.0,1.00,0.0  
2  
1,9  
60  
31,5  
.0,.3,.65,1.3,3.0  
3,5,4,3  
26.0,125.,1000.,100.0,3.0,.577  
2,4  
.769,.5,1.318,1.867,1.867,.107  
0,1,0  
2.05,.5  
.75,.2,.0  
0.,1000.  
104.,1000.  
208.,1000.  
286.,1000.  
364.,864.  
442.,680.  
520.,520.  
598.,598.  
676.,676.  
754.,754.  
858.,858.  
.02,.03  
11  
0.0,280.,.1  
2.6,220.,.1  
5.2,150.,.15  
7.8,150.,.15  
10.4,150.,.15  
13.0,150.,.15  
15.6,150.,.15  
18.2,150.,.15  
20.8,210.,.15  
23.4,360.,.1  
26.0,310.,.1  
5,6  
0.0,10.2  
35.0,10.2  
78.2,3.0  
81.2,3.0  
93.2,0.0

Table 4.3 Data Card for Sample Problem 2 (Cont'd on next page)

3,1,0,1  
1.15,0.00,0.8,360.,4.0,1.0,64.0,40.,0.0  
5,6  
5,6,0  
0.0,10.2  
35.0,10.2  
78.2,3.0  
81.2,3.0  
93.2,0.0  
0  
6,10,0  
0.0,15.2  
22.,15.2  
35.,10.2  
78.2,3.0  
81.2,3.0  
93.2,0.0  
1.15,1.2,0.8,0.,57.5,40.,0.  
5,6,0  
0.0,10.2  
35.0,10.2  
78.2,3.0  
81.2,3.0  
93.2,0.0  
1.25,0.,0.8,.0,64.,40.,0.

```

*****
*
*      CONSOLIDATION PROBLEM      *
*
*      STEP LOADING & SURCHARGE  *
*
*****

```

Abridged output for Sample Problem 2

THE PORE WATER PRESSURES ARE COMPUTED AT

YE/H	0.000	0.100	0.200	0.300	0.400
YE/H	0.500	0.600	0.700	0.800	0.900
YE/H	1.000				

XT/W	0.020	0.150	0.280	0.309	0.372
XT/W	0.475	0.578	0.641	0.675	0.851
XT/W	1.099	1.275	1.414	2.150	2.886

THE PORE PRESSURES ARE INTERPOLATED AT

XE/W=	0.000	0.100	0.200	0.300	0.400
XE/W=	0.500	0.600	0.700	0.800	0.900
XE/W=	1.000	1.100	1.200	1.300	1.400
XE/W=	1.500	1.600	1.700	1.800	1.900
XE/W=	2.000	2.100	2.200	2.300	2.400
XE/W=	2.500	2.600	2.700	2.800	2.900
XE/W=	3.000				

ASSUMING COLLOCATION POLYNOMIALS OF DEGREE

2 BETWEEN THE LIMITS	0.000 AND	0.300
4 BETWEEN THE LIMITS	0.300 AND	0.650
3 BETWEEN THE LIMITS	0.650 AND	1.300
2 BETWEEN THE LIMITS	1.300 AND	3.000

THE SUBSOIL IS DESCRIBED BY THE FOLLOWING  
PARAMETERS WHICH ARE GIVEN FOR THE UPPER LAYER  
IN CASE OF STRATIFICATION

TOTAL THICKNESS H= 26.000 FEET  
reference for X-COORD W = 100.000 FEET

LAYER INTERFACE IS 7.800 FT BELOW SURFACE  
LOWER/UPPER PERMEABILITY, RK= 0.769  
LOWER/UPPER COEF.OF.CONSOLIDATION, RC= 0.500  
LOWER/UPPER INITIAL VOID RATIO, REO= 1.318  
LOWER/UPPER COMPRESSION INDEX, RCC= 1.867  
LOWER RECOMPRESSION/UPPER RECOMPRESSION-  
-INDEX ROCL= 0.107

SKEMPTON PORE PRESSURE COEFFICIENTS ARE  
A= 0.50 AND B= 1.00

INITIAL VOID RATIO = 2.050

THE COMPRESSION INDEX IS = 0.7500E+00  
RECOMPRESSION INDEX/CC ROC= 0.200

INITIAL EFFECTIVE P AND PRECOMPRESSION  
STRESSES PC AS USED IN THE COMPUTATIONS

Y IN FT	P IN PSF	PC IN PSF
0.000	104.00	1000.00
2.600	104.00	1000.00
5.200	208.00	1000.00
7.800	286.00	1000.00
10.400	364.00	864.00
13.000	442.00	680.00
15.600	520.00	520.00
18.200	598.00	598.00
20.800	676.00	676.00
23.400	754.00	754.00
26.000	858.00	858.00

NOTE -P(1) AND PC(1) MAY HAVE BEEN CHANGED  
as compared to input values to avoid over flow

COEFF CONSOL-VERT FLOW IS CV= 0.2000E-01FT\*\*2/DAY  
COEF OF CONSOL-HORI-FLOW IS CH= 0.3000E-01FT\*\*2/DAY

THE DRAINAGE CONDITIONS ARE  
FREE DRAINAGE AT THE BOTTOM

THE SHEAR STRENGTH CHARACTERISTICS OF  
THE SUB SOIL AS USED IN THE STABILITY ANALYSIS ARE

DEPTH IN FEET	COHESION IN PSF	P-RATIO
0.000	280.000	0.100
2.600	220.000	0.100
5.200	150.000	0.150
7.800	150.000	0.150
10.400	150.000	0.150
13.000	150.000	0.150
15.600	150.000	0.150
18.200	150.000	0.150
20.800	210.000	0.150
23.400	360.000	0.100
26.000	310.000	0.100

REFERENCE LOAD  
\*\*\*\*\*

SKEMPTON PORE PRESSURE COEFFICIENTS ARE  
A= 0.50 AND B= 1.00

THE LOAD CHARACTERISTICS ARE GIVEN BY  
THE UNIT WEIGHT GLOAD= 125.00 PCF  
THE COHESION , CLOAD= 1000.00 PSF  
THICKNESS OF THE DRAINAGE BLANKET YWM= 3.00 FT  
THE TANGENT OF THE ANGLE OF INTERNAL  
FRICTION TGPHI= 0.5770  
MINP= 5 COOR POINTS XINP/YINP

0.00 FEET	10.20 FEET
35.00 FEET	10.20 FEET
78.20 FEET	3.00 FEET
81.20 FEET	3.00 FEET
93.20 FEET	0.00 FEET

THE ACTUAL LOAD IS APPROXIMATED BY 6 LOADS  
OF EQ INTENSITY WHICH EXTEND FROM X=0 TO ALPHA(I)

IF ALPHA(I) IS NEGATIVE, THIS LOAD IS SUBTRACTED

ALPHA( 1) = 89.800 FEET  
 ALPHA( 2) = 82.200 FEET  
 ALPHA( 3) = 70.700 FEET  
 ALPHA( 4) = 60.500 FEET  
 ALPHA( 5) = 50.300 FEET  
 ALPHA( 6) = 40.100 FEET

THE AVERAGE PORE PRESSURES, UAUVER(I)  
 THE CONSOLIDATION SETTLEMENTS, SETRC(I) AND  
 THE TOTAL SETTLEMENTS, SETRT(I), AT XT(I) ARE

XT FEET	UAUVER (PSF)	SETRC FT.	SETRT FT
2.01	1221.99	3.401	3.401
15.00	1220.05	3.396	3.396
27.99	1199.55	3.347	3.347
30.86	1188.66	3.321	3.321
37.21	1146.45	3.218	3.218
47.50	1001.05	2.855	2.855
57.79	831.05	2.403	2.403
64.14	708.77	2.094	2.094
67.47	658.25	1.960	1.960
85.06	361.09	1.175	1.175
109.94	118.93	0.421	0.421
127.53	71.97	0.262	0.262
141.39	49.53	0.187	0.187
215.00	6.15	0.025	0.025
288.61	0.76	0.003	0.003

THE NUMBER OF LIFTS IS NL= 3

THE AVAILABLE CONSTRUCTION TIME IS TA=

360. DAYS. TA IS NOT NEEDED IF NL=1  
 PARAMETERS USED IN THE STABILITY ANALYSIS

DMAX= 4.000 DMIN= 1.000

NARC= 5 NRAD= 6

DMAX, DMIN ARE THE MAX AND MIN STEP SIZES  
 USED IN THE SEARCH PROCEDURE

NARC=ONE- HALF THE NUMBER OF SUB ARCS

NRAD=NUMBER OF RADII USED FOR EACH TRIAL CENTER  
 OF ARCS

THE FACTOR OF SAFETY AT TIME T= 0.

DAYS FOR LIFT 1 IS FS= 1.221

AS COMPARED TO THE REQU. FSI= 1.150

FS HAS BEEN OBTAINED FOR THE ARC WITH

X= 66.00 Y= 41.00 RADIUS= 61.80 IN FT

LOAD NO 1 APPLIED AT TL= 0.DAYS

\*\*\*\*\*

SKEMPTON PORE PRESSURE COEFFICIENTS ARE

A= 0.50 AND B= 1.00

THE LOAD CHARACTERISTICS ARE GIVEN BY

THE UNIT WEIGHT GLOAD= 125.00 PCF

THE COHESION, CLOAD= 1000.00 PSF

THICKNESS OF THE DRAINAGE BLANKET YWM= 3.00 FT

THE TANGENT OF THE ANGLE OF INTERNAL



FRICTION TGPHI= 0.5770  
MINP= 5 COOR POINTS XINP/YINP  
0.00 FEET 10.20 FEET  
35.00 FEET 10.20 FEET  
78.20 FEET 3.00 FEET  
81.20 FEET 3.00 FEET  
93.20 FEET 0.00 FEET

THE REQUIRED SAFETY FACTOR IS FSI= 1.150  
THE SPECIFIED PORTION OF SETTLEMENT IS  
EQUAL TO 0.000

IF 95% OF THE AVE PORE PRESSURE  
AT THE TIME OF APPLICATION OF THIS LOAD  
HAVE DISSIPATED AT 0.8000\*15POINTS XT  
THIS LIFT IS ASSUMED TO BE THE LAST ONE

THE FACTOR OF SAFETY AT TIME T= 0.  
DAYS FOR LIFT 1 WAS .GE.FS= 1.221  
AS COMPARED TO THE REQU. FSI= 1.150

THE FACTOR OF SAFETY AT TIME T= 7.  
DAYS FOR LIFT 2 IS FS= 1.036  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 43.00 RADIUS= 62.97 IN FT  
THE FACTOR OF SAFETY AT TIME T= 14.  
DAYS FOR LIFT 2 IS FS= 1.036  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 43.00 RADIUS= 62.97 IN FT  
THE FACTOR OF SAFETY AT TIME T= 21.  
DAYS FOR LIFT 2 IS FS= 1.037  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 43.00 RADIUS= 62.97 IN FT  
THE FACTOR OF SAFETY AT TIME T= 28.  
DAYS FOR LIFT 2 IS FS= 1.037  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 43.00 RADIUS= 62.97 IN FT  
THE FACTOR OF SAFETY AT TIME T= 35.  
DAYS FOR LIFT 2 IS FS= 1.038  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 43.00 RADIUS= 62.97 IN FT  
THE FACTOR OF SAFETY AT TIME T= 42.  
DAYS FOR LIFT 2 IS FS= 1.038  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 43.00 RADIUS= 62.97 IN FT  
THE FACTOR OF SAFETY AT TIME T= 49.  
DAYS FOR LIFT 2 IS FS= 1.039  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 43.00 RADIUS= 62.97 IN FT  
THE FACTOR OF SAFETY AT TIME T= 56.

DAYS FOR LIFT 2 IS FS= 1.039  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 43.00 RADIUS= 62.97 IN FT  
THE FACTOR OF SAFETY AT TIME T= 70.  
DAYS FOR LIFT 2 IS FS= 1.040  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 43.00 RADIUS= 62.97 IN FT  
THE FACTOR OF SAFETY AT TIME T= 84.  
DAYS FOR LIFT 2 IS FS= 1.041  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 43.00 RADIUS= 62.97 IN FT  
THE FACTOR OF SAFETY AT TIME T= 98.  
DAYS FOR LIFT 2 IS FS= 1.042  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 43.00 RADIUS= 62.97 IN FT  
THE FACTOR OF SAFETY AT TIME T= 112.  
DAYS FOR LIFT 2 IS FS= 1.043  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 43.00 RADIUS= 62.97 IN FT  
THE FACTOR OF SAFETY AT TIME T= 126.  
DAYS FOR LIFT 2 IS FS= 1.044  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 44.00 RADIUS= 63.42 IN FT  
THE FACTOR OF SAFETY AT TIME T= 140.  
DAYS FOR LIFT 2 IS FS= 1.045  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 44.00 RADIUS= 63.42 IN FT  
THE FACTOR OF SAFETY AT TIME T= 154.  
DAYS FOR LIFT 2 IS FS= 1.046  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 44.00 RADIUS= 63.42 IN FT  
THE FACTOR OF SAFETY AT TIME T= 168.  
DAYS FOR LIFT 2 IS FS= 1.047  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 44.00 RADIUS= 63.42 IN FT  
THE FACTOR OF SAFETY AT TIME T= 196.  
DAYS FOR LIFT 2 IS FS= 1.048  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 44.00 RADIUS= 63.42 IN FT  
THE FACTOR OF SAFETY AT TIME T= 224.  
DAYS FOR LIFT 2 IS FS= 1.050  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 44.00 RADIUS= 63.42 IN FT  
THE FACTOR OF SAFETY AT TIME T= 252.  
DAYS FOR LIFT 2 IS FS= 1.052  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 44.00 RADIUS= 63.42 IN FT  
THE FACTOR OF SAFETY AT TIME T= 280.

DAYS FOR LIFT 2 IS FS= 1.054  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 44.00 RADIUS= 63.42 IN FT  
THE FACTOR OF SAFETY AT TIME T= 308.  
DAYS FOR LIFT 2 IS FS= 1.055  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 44.00 RADIUS= 63.42 IN FT  
THE FACTOR OF SAFETY AT TIME T= 336.  
DAYS FOR LIFT 2 IS FS= 1.057  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 44.00 RADIUS= 63.42 IN FT  
THE FACTOR OF SAFETY AT TIME T= 364.  
DAYS FOR LIFT 2 IS FS= 1.059  
AS COMPARED TO THE REQU. FSI= 1.150  
FS HAS BEEN OBTAINED FOR THE ARC WITH  
X= 57.50 Y= 44.00 RADIUS= 63.42 IN FT

EITHER THE FACTOR OF SAFETY, FS= 1.059  
AND/OR THE SETTLEMENT, SETC(1)= 0.751FEET  
ARE LESS THAN SPECIFIED AT TIME T= 364.DAYS  
WHICH IS GREATER THAN TA= 360.DAYS  
\*\*\* THIS LIFT NO 1 IS, THEREFORE  
CONSIDERED TO BE THE LAST ONE\*\*\*

THE CONSOL. PROCESS  
\*\*\*\*\*

THE FOLLOWING INFORMATION IS OUT PUT  
UAVE(X(1)),UAVE(X(2)),.....,  
= AVER DEGREES OF CONSOL. WITH RESPECT TP REF. LOAD  
SETC(X(1)),SETC(X(2)),.....,  
= CONSOL. SETTLEMENTS  
SETI(X(1)),SETI(X(2)),.....,  
= IMMEDIATE SETTLEMENTS  
SETT(X(1)),SETT(X(2)),.....,  
= CONSOLI. + IMMEDIATE SETTLEMENTS  
LAST TWO LINE ARE ONLY OUT PUT  
IF SOIL IS PARTIALLY SATURATED (B.NE.1.)  
THE POINTS X(I) IN FEET ARE AS FOLLOWS

0.000 80.000

T= 0.  
DAYS IS THE TIME OF LOAD APPLICATION

T= 0. DAYS

0.000 0.000  
0.000 0.000

T= 7. DAYS

0.087 0.072  
0.361 0.154

T= 14. DAYS

0.091 0.075  
0.377 0.160

T= 21. DAYS

0.095 0.078  
0.392 0.167

T= 28. DAYS

0.098 0.081  
0.405 0.172

T= 35. DAYS

0.102 0.084  
0.418 0.178

T= 42. DAYS

0.106 0.087  
0.430 0.183

T= 49. DAYS

0.109 0.090  
0.441 0.188

T= 56. DAYS

0.112 0.092  
0.452 0.193

T= 70. DAYS

.119 0.098  
.472 0.202

T= 84. DAYS

.125 0.103  
.490 0.210

T= 98. DAYS

.131 0.108  
.508 0.219

T= 112. DAYS

.137 0.112  
.525 0.226

T= 126. DAYS

.143 0.117  
.541 0.234

T= 140. DAYS

.148 0.121  
.557 0.241

T= 154. DAYS

.153 0.125  
.571 0.248

T= 168. DAYS

.159 0.129  
.586 0.254

T= 196. DAYS

.168 0.137

0.613 0.267

T= 224. DAYS

0.177 0.145  
0.639 0.278

T= 252. DAYS

0.186 0.152  
0.663 0.289

T= 280. DAYS

0.194 0.158  
0.686 0.300

T= 308. DAYS

0.202 0.165  
0.709 0.310

T= 336. DAYS

0.210 0.171  
0.730 0.319

T= 364. DAYS

0.217 0.177  
0.751 0.328

T= 392. DAYS

0.224 0.182  
0.771 0.337

T= 448. DAYS

0.237 0.193  
0.808 0.354

T= 504. DAYS

.250	0.203
.844	0.370

T= 560. DAYS

.262	0.213
.878	0.385

T= 616. DAYS

273	0.222
910	0.399

T= 672. DAYS

283	0.231
941	0.413

T= 728. DAYS

293	0.239
970	0.426

AVE DEGREE OF CONSOL. AND SETTLEMENT  
CURVES FOR POINT X= 0.00FEET FROM CENTER LINE  
INTERVAL BETWEEN 2 GRID LINES.EQ.10%  
ABSCISSA NUMBERS GIVE THE TIME IN WKS  
THE TOTAL SETTLE DUE TO REFERENCE LOAD IS= 0.340E+01FT  
U -CUREV= AVE. DEGREE OF CONSOL.  
RELATIVE TO THE PORE PRESS DUE TO REF LOAD  
C -CURVE=CONSOL. SETTLE. IN % OF REF. SETTLEMENT

g. 4.7(a)

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5

```
*****I*****I*****I*****I*****I*****I*****I*****I*****I*****I*****  
UC                                                                                      *  
    UC                                                                                  *  
        UC                                                                            *  
            UC                                                                      *  
                UC                                                                *  
                    UC                                                            *  
                        UC                                                         *  
                            UC                                                     *  
                                UC                                                  *
```









APPENDIX - A

PROGRAM MSAND

C FORT1 and FORT2 are internal files.

C INPUT and OUTPUT files must be specified by the USER.

C \*\*\*\*\*

C THIS PROGRAM OPTIMIZES THE RATE AT WHICH A SPECIFIC HIGHWAY  
C EMBANKMENT CAN BE CONSTRUCTED ON SOFT SUBSOIL. THIS PROBLEM  
C INVOLVES THE COMPUTATION OF STRESSES AND PORE PRESSURES IN  
C THE SUBSOIL, THE DISSIPATION OF THESE PORE PRESSURES, THE  
C CORRESPONDING INCREASE IN SHEAR RESISTANCE AND THE STABILITY  
C OF THE EMBANKMENT.

C THE EMBANKMENT LOAD WHICH IS ASSUMED TO ACT VERTICALLY,  
C INDUCES PORE PRESSURES IN THE SUBSOIL WHICH ARE COMPUTED USING  
C THEORY OF ELASTICITY AND SKEMPTON-PORE PRESSURE PARAMETERS  
C A AND B. THESE PORE PRESSURES DISSIPATE ACCORDING TO THREE  
C DIMENSIONAL CONSOLIDATION THEORY WHICH TAKES INTO ACCOUNT  
C THE EFFECT OF GAS AND VARIABLE SOIL PARAMETERS. AS THE PORE  
C WATER PRESSURE DISSIPATES THE EFFECTIVE STRESSES IN THE SUB-  
C SOIL WILL INCREASE GIVING A SIMULTANEOUS INCREASE IN SHEARING  
C RESISTANCE. SETTLEMENTS ARE COMPUTED FROM THE DISSIPATED PORE  
C PRESSURES.

C \*\*\*\*\*

Character\*50 INPUTFILE,OUTPUTFILE

REAL KVO,KHO

DIMENSION AX(5),JSP(10),MXE(4),MXT(4),MXS(4),OMEGA(40),OMED(40)  
DIMENSION PHI(20),PHID(20),R(510),SETC(20),SETI(20),SETT(20)  
DIMENSION SETRC(20),SETRI(20),SETRT(20),SPECS(10),SPECU(10)  
DIMENSION T(150)  
DIMENSION TB(50),TL(10),UA(220),UB(220),UC(220),UD(220),UAVE(20)  
DIMENSION UAUVER(20),XE(51),XME(660),XMT(100),XINP(20),XRP(20)  
DIMENSION YE(11),YINP(20),YRP(20),RSP(100),UAVED(20)  
DIMENSION SETR(20),ROW(100),KK(20),SYMB(4),XT(20),SV(11)  
DIMENSION SVM(12),P(11),PC(11),PLOG(11),CO(11)  
DIMENSION CP(11),SU(561),UAVEM(20),UM(220),UU(220),IDEN(10)  
DIMENSION UE(40),UF(40)

EQUIVALENCE (UA(1),XME(1)),(UB(1),XME(221))

EQUIVALENCE (UC(1),XME(441)),(UD(1),XMT(1))

COMMON/ SAPOD/ IOUTP,W,HH,GLOAD,CLOAD,NARC,NRAD  
COMMON/ SADI1/ LAYER,IBCV,MHE,M,N,IDC,NDR,ISUM,XET(41)  
COMMON/ SADI2/ FIMPV,RC,RK,C,RO,RE,TA,ISP,IVAR  
COMMON/ SACSE/ ROC,ROCL,SVM,P,PC,PLOG,PO,PCO,IAV,IK,ISAT,AAV,AA  
COMMON/ SACO1/ AVOC,KVO,KHO,EOPUS,PU,SKHM,SKVM,CCC,NNN,ICOEF  
COMMON/ SACO2/ PCV(10),CVIN(10),PCH(10),CHIN(10),ICV,KOUNT,HF  
COMMON/ SADET/ XSTAB(51),YSTAB(11),DX,DY,YWM,TGPHI

DATA (TB(I),I=1,45)/

1 0., 7., 14., 21., 28., 35., 42., 49., 56.,  
2 70., 84., 98., 112., 126., 140., 154., 168., 196.,  
3 224., 252., 280., 308., 336., 364., 392., 448., 504.,  
4 560., 616., 672., 728., 819., 910., 1001., 1092., 1274.,  
5 1456., 1638., 1820., 2184., 2548., 2912., 3276., 3640., 7280./

C Specify the INPUTFILE and OUTPUTFILE Names.

INPUT=3

IOUTP=4

C

WRITE (\*,1132)

1132 FORMAT ('---Specify the Name of your INPUTFILE')

READ (\*,1133)INPUTFILE

WRITE (\*,1134)

1134 FORMAT ('---Specify the Name of the OUTPUTFILE')

READ (\*,1133)OUTPUTFILE

1133 FORMAT (a50)

OPEN (UNIT=3,FILE=INPUTFILE,STATUS='OLD')

REWIND (3)

OPEN (UNIT=4,FILE=OUTPUTFILE,STATUS='NEW',FORM='FORMATTED')

REWIND (4)

WRITE (\*,1131)

1131 FORMAT ('Specify the No. of Symbols to be used in the plot')

C The Following symbols are proposed for the user to input.

C Blank = a Blank Space

C STAR = \*

C GRID = I

C SYMB (1) = U --For Ave. Deg. of Consolidation.

C ' 2 = C --For Consol. Settlement.

C ' 3 = O --For Imm. ' .

C ' 4 = T --For Total ' .

READ (\*,\*) MMM

WRITE (\*,1130)

1130 FORMAT('Specify Characters-Blank,STAR,GRID,(SYMB(I),1,MMM)')

READ (\*,194)BLANK,STAR,GRID,(SYMB(I),I=1,MMM)

C

C

C DETERMINATION OF MESH POINTS FOR FINITE DIFFERENCE SCHEME AND  
C STABILITY ANALYSIS.C MYE.LE.12,MHE.LE.40: Number of vertical and horizontal points  
C in the finite difference scheme. HF=1.-for horizontal flow

C POR=Horizontal drainage distance/(XT(IEND)\*W).

C POR-the distance to the zero pore pressure in H dirn from  
C the center line.Put IPOR=1(if POR is input by the user).

C Put POR=1.0 and IPOR=0 then the program will determine POR

C \*\*\*\*\*

999 READ (INPUT,\*)MYE,MHE,ITBL,ISP,HF,POR,IPOR

IF (ITBL.LE.0) ITBL=45

IF (ITBL.GT.45) ITBL=45

C MMM Total no. of SYMB (Symbols) to be used in the output

IF (ISP.EQ.1) GOTO 9001

C Read no. of points for which output is required,if ISP=0.

C If ISP=1 (special points), output the data for points XT.

read (INPUT,\*) JND

read (INPUT,\*) (JSP(K),K=1,JND)

C LND = No. of lines to be printed.

C (i.e No. of weeks on the time axis in the output)

9001 continue

READ (INPUT,\*)LND

C

C GENERATE THE MATHEMATICAL MOLECULE FOR SIMPSONS OR TRAPEZOIDAL  
C RULE IN VERTICAL DIRECTION.

C

CALL GENS (SV,MYE)

C

C GENERATE VECTOR YE

C

MT=MYE-1

```

      D=MT
      D=1./D
      DO 11 I=1,MT
      AI=I-1
11    YE(I)=AI*D
      YE(MYE)=1.
      IF (ISP.EQ.1) GOTO 1
C
C  READ NUMBERS OF EQUIDISTANT POINTS, MX, IN X-DIRECTION, NUMBER
C  OF INTERVALS, NI, AND INTERVAL LIMITS AX(I), I=1,NI.
C  THESE LIMITS ARE DIMENSIONLESS. TO GET THE CORRESPONDING VALUES
C  IN FEET, THE AX(I) ARE MULTIPLIED BY THE REFERENCE VALUE W WHICH
C  IS INPUT LATER.
C
      READ (INPUT,*) MX,NI
      NIM=NI-1
      READ (INPUT,*) (AX(I),I=1,NI)
C
C  READ NUMBER OF UNEQUALLY SPACED POINTS IN EACH INTERVAL, MXT(I),
C  GENERATE THE POINTS XT, IF ISP=0
C
      READ (INPUT,*) (MXT(I),I=1,NIM)
      IEND=0
C
C  GENERATE XT-S
C
      DO 21 J=1,NIM
      MT=MXT(J)
      ISTT=IEND+1
      IEND=IEND+MT
      D=2*MT
      AS=AX(J+1)+AX(J)
      AD=AX(J+1)-AX(J)
      DO 22 I=ISTT,IEND
      AI=2*(IEND-I)+1
22    XT(I)=(AD*COS(AI*3.14159265358979/D)+AS)/2.
21    CONTINUE
      GOTO 2
C
C  READ SPECIAL POINTS IF ISP=1
C  IEND must be atleast 6 and 4 points be directly under the main
C  embankment.
      I  READ (INPUT,*) IEND
      READ (INPUT,*) (XT(I),I=1,IEND)
      GOTO 42
C
C  Generate equidistant points in x-dirn including the limits
C  AX(1) and AX(NI). Determine the number of XE-s in each interval
C  MXE(I). If the left limit of the I-th interval coincides with
C  an XE(K), the limit is considered in MXE(I).
C
2    MT=1
      J=2
      MM=MX-1
      D=MM
      D=(AX(NI)-AX(1))/D
      XE(1)=AX(1)
      DO 23 I=2,MM

```

```

XE(I)=XE(I-1)+D
IF (XE(I).LT.(AX(J)-0.001)) GO TO 23
MXE(J-1)=I-MT
MT=I
J=J+1
23 CONTINUE
XE(MX)=AX(NI)
MXE(J-1)=MX+1-MT

```

C  
C INITIATE THE DETERMINATION OF MATRICES XMT,XME AND R  
C

```

IEND=0
JEND=0
IRND=0
DO 41 J=1,NIM

```

C GENERATE MATRIX XMT FROM XT-S AND INVERT XMT  
C

```

ISTT=IEND+1
IEND=IEND+MXT(J)
PAGE 4
CALL MATR (ISTT,IEND,MXT(J),XT,AX(J),XMT)
CALL MINV (XMT,MXT(J),DETER)

```

C  
C Generate matrix XME from XE-s  
C

```

JSTT=JEND+1
JEND=JEND+MXE(J)
CALL MATR (JSTT,JEND,MXT(J),XE,AX(J),XME)

```

C Post multiply the inverse of matrix XMT, which is stored in  
C array XMT, by matrix XME, and store the result in matrix R  
C starting with element R(IRST).  
C

```

IRST=IRND+1
IRND=IRND+MXT(J)*MXE(J)
CALL MPRD (XMT,XME,R,MXT(J),MXT(J),MXE(J),1,1,IRST)

```

```

41 CONTINUE
42 AIEND=IEND

```

C  
C NOTE THAT THE LAST VALUE OF IEND IS EQUAL TO THE TOTAL  
C NUMBER OF XT-S.  
C

C  
C INPUT DATA FOR A SPECIFIC CASE.  
C \*\*\*\*\*

C  
C Read thickness of soil layer,H,Unit weight of the embankment  
C load,GLOAD,Undrained strength of the embankment material CLOAD,  
C Reference length in H-dirn,W,Thickness of the drainage blanket,  
C YWM,Tangent of angle of internal friction,TGPHI.  
C If H=0.0 the program is terminated.  
C

```

100 READ (INPUT,*) H,CLOAD,CLOAD,W,YWM,TGPHI
   IF (H.EQ.0.) GOTO 10000
   IF (H.EQ.99.) GOTO 999
   HH=H

```

C  
C IDC=1 vertical flow only in all XT-s  
C IDC=2 vertical + horizontal flow.  
C

```

IDC=2

```

```

      IF (HF.EQ.0.) IDC=1
C   DETERMINE INCREMENTS IN VERTICAL AND HORIZONTAL DIR
C   -ECTION, DY AND DHX
45      DY=MYE-1
          DY=H/DY
          DYSQ=DY*DY
C
C   Read drainage identifier IBCV
C   IBCV=1   Impeded drainage at Y=H,
C   IBCV=2   Free drainage at Y=H,
C   IBCV=3   No drainage at Y=H
C   Read location of interface in case of inhomogeneous soil,
C   4.LE.LAYER.LE.MYE-3
C
          READ (INPUT,*)IBCV,LAYER
          N=MHE-1
          M=MYE-2
          IF (IBCV.EQ.3) M=MYE-1
          IF (IBCV.EQ.2) FIMPV=0.
          IF (IBCV.GT.1) GO TO 4
C
C   Read thickness of impedance layer,HI,and ratio of permeabilities,
C   RKV=K(drainng soil,vertical)/K(impedence layer,vertical)
C
          READ (INPUT,*)HI,RKV
          CHIV=RKV*HI/DY
          FIMPV=CHIV/(1.+CHIV)
4      IF (HF .EQ. 0.) GO TO 7
C   Determine the horizontal grid point to be used in the finite
C   difference scheme.
C
          AI=MHE-1
          DHX=POR*XT(IEND)*W/AI
          IAI=AI
          DO 25 I=1,IAI
          XET(I)=POR*(I-1)*XT(IEND)/AI
25      CONTINUE
          DXSQ=DHX*DHX
C   Check for layer interface. Read ratio of permeabilities, RK=
C   K(lower)/K(upper), and ratio of coeff. of consolidation, RC=
C   CV(lower)/CV(upper),REO=EO(lower)/EO(upper)=Ratio of initial
C   void ratios, RAV=AVO(lower)/AVO(upper)=Ratio of coeff. of
C   compress., RCC=(cc(lower layer)/cc(upper layer)=Ratio of
C   compression indices. ROCL=cc(recompression,lower)/cc(upper)
C
7      IF (LAYER .LT. 3) GOTO 6
          READ (INPUT,*)RK,RC,REO,RAV,RCC,ROCL
          IF (LAYER .GT. (MYE-3)) LAYER=0
C
C   Read identifiers and parameters for the compressible layer
C   IVAR=0 Const. soil parameters in the consolidation process.
C   IVAR=1 Variable soil parameter in the consolidation process.
C   ISAT=0 100% saturation.
C   ISAT=1 Partial saturation.
C   IAV=0 Const. coeff. of compressibility.
C   IAV=1 Variable coeff. of compressibility.
C   ICV=0 Vectors of coeff of consolidation are not input.
C   ICV.GT.0 Vectors of coef. of consol. are input. Variable
C           CV and CH are obtained in subroutine COEFF by
C           interpolation.

```



```
C IK=0    Const. coeff. of permeability.
C IK=1    Variable coeff. of permeability.
C
C EO Initial void ratio.
C KVO Initial vertical permeability.
C KHO Initial horizontal permeability.
C AVO Initial coeff of compressibility.
C A,B Skempton Pore pressure coefficients.
C CC Compression index of the virgin part of the E Vs LOG(P)
C curve.
C ROC (Recompression index)/CC in case of consolidation.
C GAMMA Buoyant unit weight for computing initial eff. stress.
C P(I) Initial effective stresses.
C PC(I) Precompression stresses.
C CV,CH Vertical and Horizontal coeff. of consol.
C S Degree of saturation.
C PU Initial Gas pressure.
C SKV,SKH Slopes of the void ratio Vs LOG(permeability) curve.
C
6      READ (INPUT,*) IVAR,IAV,ICV
      IF (ICV .NE. 0) IVAR=1
      READ (INPUT,*) EO,A
      ALPHG=1.
      B=1.
      IF (IAV .EQ. 1) GOTO 350
      READ (INPUT,*) AVO
      GOTO 563
C
C Read cc, ROC and GAMMA. If GAMMA.NE.0., Initial eff stresses,P,
C are computed and normal consol. is assumed. If GAMM=0., initial
C and precompression stresses are input.
C
350    READ (INPUT,*) CC,ROC,GAMMA
      IF (GAMMA .EQ. 0.) GOTO 561
C
C Initial eff stresses are computed. PO and PCO are averages
C
      AD=DY*GAMMA
      P(1)=AD
      PC(1)=AD
      PLOG(1)=0.
      PO=GAMMA*H/2.
      PCO=PO
      AI=0.
      DO 565 I=2,MYE
      AI=AI+AD
      P(I)=AI
      PC(I)=AI
      PLOG(I)=0.
565    CONTINUE
      GO TO 563
C
C Initial eff. and precompression stresses are input.
C
561    READ (INPUT,*) P(1),PC(1)
      PO=SV(1)*P(1)
      PCO=SV(1)*PC(1)
      DO 562 I=2,MYE
      READ (INPUT,*) P(I),PC(I)
      PO=PO+SV(I)*P(I)
```

```

      PCO=PCO+SV(I)*PC(I)
      PLOG(I)=ALOG(PC(I)/P(I))
562   CONTINUE
      IF (P(1) .EQ. 0.) P(1)=P(2)
      IF (PC(1) .EQ. 0.) PC(1)=PC(2)
      PLOG(1)=ALOG(PC(1)/P(1))
C If constant parameters are to be used in the cosol. process
C read CV,CH,AVO. If variable parameters are to be used,IF IVAR=1
C read necessary coeffs.
C
563   IF (IVAR .EQ. 1) GOTO 564
      READ (INPUT,*) CV,CH
      GOTO 30
564   IF (ICV .EQ. 0) GOTO 572
      DO 573 I=1,ICV
573   READ (INPUT,*) PCV(I),CVIN(I),PCH(I),CHIN(I)
      GOTO 574
572   READ (INPUT,*) KVO,KHO
574   IF (IAV .EQ. 1) GOTO 566
      AVOC=AVO
      PO=0.
      PCO=0.
566   READ (INPUT,*) ISAT,IK
      IF (ISAT.EQ.0) GOTO 567
      READ (INPUT,*) S,PU,HC,B
      IF (PU.EQ.0.) PU=2117.+62.43*H/2.
      EOPS=EO*PU*(1.-S*(1.-HC))
567   IF (IK.EQ.1) READ (INPUT,*) SKV,SKH
30    CONTINUE
C
C Read NC initial shear strengths CO(I) and C/PBAR-ratios
C at arbitrary depths Y(I). if NC.EQ.MYE, the depths are
C assumed to be equal to H*YE(I). IF NC.LE.MYE the values
C of CO(J) and PC(J) at H*YE(J) are obtained by interpolation.
C The input values are not saved.
C
      IF (ISP.EQ.1) GOTO 585
      READ (INPUT,*) NC
      DO 580 I=1,NC
      READ (INPUT,*) Y,UA(I),UB(I)
580   YRP(I)=Y/H
      IF (NC.EQ.MYE) GOTO 581
      CALL LAGR (YE,CO,MYE,1,YRP,UA,NC)
      CALL LAGR (YE,CP,MYE,1,YRP,UB,NC)
      GOTO 582
581   DO 583 I=1,MYE
      CO(I)=UA(I)
583   CP(I)=UB(I)
C
C Define the vectors XSTAB and YSTAB which are needed in the
C stability analysis.
C
582   DO 584 I=1,MX
584   XSTAB(I)=W*XE(I)
      DX=XSTAB(2)-XSTAB(1)
C
      DO 586 I=1,MYE
586   YSTAB(I)=H*YE(I)
585   CONTINUE
C

```

C OUTPUT OF DATA INPUT SO FAR. FOR FORMAT STATEMENTS  
C SEE END OF PROGRAM  
C \*\*\*\*\*  
C

```

WRITE (IOUTP,901)
WRITE (IOUTP,900)
WRITE (IOUTP,903)
WRITE (IOUTP,900)
WRITE (IOUTP,904)
WRITE (IOUTP,902)
WRITE (IOUTP,905) (YE(I),I=1,MYE)
WRITE (IOUTP,902)
WRITE (IOUTP,906) (XT(I),I=1,IEND)
WRITE (IOUTP,902)
IF (ISP.EQ.1) GOTO 53
WRITE (IOUTP,907)
WRITE (IOUTP,902)
WRITE (IOUTP,908) (XE(I),I=1,MX)
WRITE (IOUTP,909)
DO 51 I=1,NIM
MM=MXT(I)-1
51 WRITE (IOUTP,910) MM,AX(I),AX(I+1)
WRITE (IOUTP,902)
53 WRITE (IOUTP,901)
WRITE (IOUTP,902)
WRITE (IOUTP,913)
WRITE (IOUTP,914)H,W
WRITE (IOUTP,902)
IF (LAYER.LT.3) GOTO 54
AI=YE(LAYER)*H
WRITE (IOUTP,915) AI,RK,RC,REO
IF (IAV. EQ.0) GOTO 551
WRITE (IOUTP,715)RCC,ROCL
GOTO 552
551 WRITE (IOUTP,815) RAV
552 WRITE (IOUTP,902)
54 WRITE (IOUTP,916) A,B
IF ((1.-B).LT.0.00001) GOTO 55
WRITE (IOUTP,917) S,HC,PU
WRITE (IOUTP,902)
55 WRITE (IOUTP,918) EO
WRITE (IOUTP,902)
IF (IAV.EQ.1) GO TO 553
WRITE (IOUTP,818)AVO
WRITE (IOUTP,902)
GOTO 554
553 WRITE (IOUTP,919)CC,ROC
WRITE (IOUTP,819)
DO 555 I=1,MYE
AI=YE(I)*H
WRITE (IOUTP,719) AI,P(I),PC(I)
555 CONTINUE
WRITE (IOUTP,619)
WRITE (IOUTP,902)
554 IF (IVAR.EQ.1) GOTO 556
WRITE (IOUTP,934) CV,CH
GOTO 57
556 IF (ICV.EQ.0) GOTO 575
WRITE (IOUTP,820)
DO 576 I=1,ICV

```

```

576  WRITE(IOUTP,720)PCV(I),CVIN(I),PCH(I),CHIN(I)
      GOTO 57
575  WRITE (IOUTP,920) KVO,KHO
      IF (IK.EQ.1) WRITE (IOUTP,921)SKV,SKH
57   WRITE (IOUTP,902)
      WRITE (IOUTP,922)
      IF (IBCV.NE.1) GOTO 61
      WRITE (IOUTP,926)H1,RKV
      GOTO 64
61   IF (IBCV.EQ.3) GOTO 63
      WRITE (IOUTP,927)
      GOTO 64
63   WRITE (IOUTP,928)
C
64   WRITE (IOUTP,902)
      IF (ISP.EQ.1) GOTO 587
      WRITE (IOUTP,961)
      DO 588 I=1,MYE
588  WRITE (IOUTP,962) YSTAB(I),CO(I),CP(I)
587  WRITE (IOUTP,900)
C
C Define the modified molecules SVM in vertical direction.
C Redefine ROCL to be the ratio of the Recompression index
C of the lower layer and the compression index of the virgin
C part of the lower layer.
C Redefine also the parameters KKK,KIAV,NNN,FUP,FLO,SKVM,SKHM
C CCC,AAV,AAH and ICOEFF, which are needed in subroutines SETL
C and COEFF.
C Redefine also PCV,PCH,CVIN,CHIN in case that ICV.NE.0
C
      AI=1.+EO
      AAV=AI/(62.42796*DYSQ)
      IF (HF.EQ.0.) GOTO 521
      AAH=AI/(62.42796*DXSQ)
521  KKK=MYE
      KIAV=IAV+1
      NNN=1
      AD=H
      IF (LAYER.GE.3) GOTO 524
      DO 523 I=1,MYE
523  SVM(I)=SV(I)
      GOTO 522
524  KKK=LAYER
      CALL GENS(SVM,KKK)
      MM=MYE-LAYER+1
      CALL GENS(UA,MM)
      II=LAYER
      DO 525 I=1,MM
      II=II+1
525  SVM(II)=UA(I)
      AS=1.+EO*REO
      IF (RCC.NE.0.) ROCL=ROCL/RCC
      AD=H*YE(LAYER)
522  ICOEF=1
      IF (IK.EQ.1) ICOEF=2+IAV
      IF (ICV.EQ.0) GOTO 530
      ICOEF=4
      DO 529 I=1,ICV
      PCV(I)=ALOG(PCV(I))
      CVIN(I)=CVIN(I)/DYSQ

```

```
IF (HF.EQ.0.) GOTO 529
PCH(I)=ALOG(PCH(I))
CHIN(I)=CHIN(I)/DXSQ
```

```
529 CONTINUE
530 IF (IAV.EQ.1) GOTO 527
```

C  
C Coeff. of compressibility is const (IAV=0)  
C

```
FUP=AD*AVO/AI
IF (LAYER.GE.3) FLO=(H-AD)*AVO*RAV/AS
IF (IK.EQ.0) GOTO 520
SKVM=2.302585*AVO/SKV
IF (HF.EQ.0.) GOTO 520
SKHM=2.302585*AVO/SKH
GOTO 520
```

C  
C Variable coeff. of compressibility IAV=1.  
C

```
527 CCC=0.4342945*CC
AVOC=CCC/PCO
IF (PCO.GT.PO) AVOC=AVOC*(PCO/PO)**ROC
FUP=AD*CCC/AI
IF (LAYER.GE.3) FLO=(H-AD)*CCC*RCC/AS
IF (IK.EQ.0) GOTO 520
SKVM=CC/SKV
IF (HF.GT.0.) SKHM=CC/SKH
```

C  
C  
C  
C REFERENCE LOAD.  
C \*\*\*\*\*  
C  
C Read characteristics of the reference load.  
C XINP,YINP -the coordinates of the polygon which describes  
C the load.  
C MINP- The no. of points.  
C NS- The no. of strips by which the actual load is approximated.  
C

```
520 READ (INPUT,*)MINP,NS
WRITE (IOUTP,935)
WRITE (IOUTP,916) A,B
WRITE (IOUTP,930) GLOAD,CLOAD,YWM,TGPHI,MINP
DO 101 I=1,MINP
READ (INPUT,*) XINP(I),YINP(I)
101 WRITE (IOUTP,931) XINP(I),YINP(I)
```

C  
C Compute the pore water pressures at (XT(I),I=1,IEND)/YE(J),J=1,MYE)  
C  
C

```
CALL PORE (XINP,YINP,MINP,NS,XT,IEND,YE,MYE,UB,A,B)
```

C determine the horizontal distance from the Center line to the point  
C where the pore pressure is 0.1% of the max pore pressure under the  
C embankment. This is taken as a free drainage end.

```
CALL HDIST (UB,XT,IEND,ICV,CHIN,DXSQ,AAH,MHE,W,XET,IPOR,
* HF,MYE,POR)
IPOR=1
```

C  
C  
C Compute the average pore pressures UAVER(I),I=1,IEND for the  
C reference load. Determine final consolidation settlements,SETREC(I),

C Immediate settlements, SETRI(I), and Total settlements (SETRT(I),  
C I=1,IEND for the reference load.

```
C
      II=0
      DO 501 I=1,IEND
      UAVER(I)=0.
      DO 102 J=1,MYE
      II=II+1
      UU(II)=UB(II)
102    UAVER(I)=UAVER(I)+UB(II)*SV(J)
501    CONTINUE
```

```
C
      CALL SETL (UB,SETRC,IEND,KKK,MYE,1.,FUP,FLO,KIAV)
      IF (B.NE.1.) GOTO 513
      DO 514 I=1,IEND
      SETRT(I)=SETRC(I)
514    SETRI(I)=0.
      GOTO 515
513    FAC=1./B
      CALL SETL (UB,SETRT,IEND,KKK,MYE,FAC,FUP,FLO,KIAV)
```

```
C
C Define initial parameters.
C TL(LIFT) Time of LIFT-th load application.
C TB(ITB) Time from TL(LIFT) till TL(LIFT+1) given in DATA
C statement.
C Y(IT) Time from first load application, T(IT)=TL(LIFT)
C +TB(ITB)
```

```
C
515    WRITE (IOUTP,932)
      DO 71 I=1,IEND
      AI=W*XT(I)
      WRITE(IOUTP,933)AI,UAVER(I),SETRC(I),SETRT(I)
71    CONTINUE
      WRITE (IOUTP,900)
      ISUM=MYE*IEND
      LIFT=1
      LL=LIFT+1
      ITB=1
      IT=1
      TL(1)=0.
      TB(1)=0.
      T(1)=0.
```

```
C
C Read no. of lifts,NL. If computation for special points is required
C (ISP=1), read also NL times of load application,TL.
C NLS is defined for checking purposes at the end of the program
C IDEN(1).LT.0, Pore pressures due to the first load are set
C equal zero.
C IDEN(I)=0, , I=1,NL pore pressures due to the I-th load are4
C computed by means of subroutine PORE.
C IDEN(I)=1, I=1,NL PORE pressures due to the I-th load are
C set equal to those due to the REFERENCE load.
```

```
C
      READ (INPUT,*) NL,(IDEN(I),I=1,NL)
      NLS=NL
      WRITE (IOUTP,936) NL
      WRITE (IOUTP,902)
      IF (ISP.EQ.0) GOTO 103
      READ (INPUT,*) (TL(I),I=1,NL)
      WRITE (IOUTP,937)
```

```

DO 106 I=1,NL
106  WRITE (IOUTP,938) I,TL(I)
      WRITE (IOUTP,902)
      T(I)=TL(I)+TB(I)
      GOTO 105

C
C FIRST LOAD.
C *****
C
C Read characteristics of the first load, also
C TA   Available construction time.
C SPECS Specified settlement for the first lift.
C SPECU When the NOT DISSIPATED average pore pressures
C        become less than 5% of the total average pore pressure
C        at the time of load application at IEND*SPECU points,
C        the subsequent loads are disregarded.
C FSI   Factor of safety for the first lift.
C DMAX  max. interval used in the search for the minimum FS
C DMIN  Corresponding minimum interval.
C ZZ    Distance between the maximum YINP and the minimum
C        permissible YC during the search procedure.
C NARC  One-half the no. of subarcs used in subroutine DETFS
C NRAD  No. of trial arcs used at each center YC,YC
C IAB=0 Use A and B as defined earlier.
C IAB.NE.0 Read new values of A and B.
C
103  READ (INPUT,*) FSI,SPECS(1),SPECU(1),TA,DMAX,DMIN,XC,YC,ZZ
      READ (INPUT,*) NARC,NRAD
      IF (DMAX.GT.DMIN) GOTO 401
      DMAX=H/2.
      DMIN=H/20.
401  WRITE (IOUTP,940) TA
      WRITE (IOUTP,840) DMAX,DMIN,NARC,NRAD
105  READ (INPUT,*) MINP,NS,IAB
      DO 506 I=1,MINP
506  READ (INPUT,*)XINP(I),YINP(I)
      IF (IAB.NE.0) READ (INPUT,*) A,B
      IF (ISP.EQ.1) GOTO 107

C
C CALL SUBROUTINES FOR STABILITY ANALYSIS
C
      CALL INIT (XINP,YINP,MINP,XC,YC,YY,ZZ,DMIN)
      CALL GAIN (UA,R,SU,MYE,MXT,MXE,MX,NIM,CO,CP,1)
      CALL STAB (XC,YC,RR,XINP,YINP,MINP,MX,MYE,SU,FS,DMAX,DMIN,YY)
      DO 570 I=1,ISUM
570  UA(I)=0.

C
      WRITE (IOUTP,942) T(IT),LIFT,FS,FSI
      WRITE (IOUTP,842) XC,YC,RR
      IF (FS.GE.FSI) GOTO 107
      WRITE (IOUTP,943)

C
C Since Branching to the input of a new case might result in the
C reading of the following load characteristics instead of the
C data for a new run, the program is terminated here.
C
      GOTO 10000
107  WRITE (IOUTP,902)

C
C RESIDUAL PORE PRESSURES

```

```
C *****
C
C Read index IRP and, for IRP.NE.0 residual pore pressures.
C
C IRP=0 No residual pore pressures.
C IRP=1 Residual pore pressures at XT/YE are input.
C IRP=2 Residual pore pressures at points other than XY/YE
C are input.
C
      READ (INPUT,*) IRP
      IF (IRP-1) 109,110,111
C
C NO RESIDUAL PORE PRESSURES
C
  109      DO 112 J=1,ISUM
  112      UC(J)=0.
          GO TO 108
C
C Residual pore pressures at points XT/YE. Input is columnwise
C with each input card containing ten values
C
  110      READ (INPUT,*) (UC(I),I=1,ISUM)
          WRITE (IOUTP,944) (YE(J),J=1,MYE)
          II=1-MYE
          IJ=0
          DO 113 I=1,IEND
          II=II+MYE
          IJ=IJ+MYE
  113      WRITE (IOUTP,945) I,XT(I),(UC(J),J=11,IJ)
          GOTO 108
C
C Residual pore pressures at points other than XT/YE. Residual
C pore pressures at XT/YE are obtained by interpolation. The
C input values are not saved.
C
  111      WRITE (IOUTP,946)
          I=1
          J=1
          READ (INPUT,*) X,Y,UA(1),COUNT
          WRITE (IOUTP,947) X,Y,UA(1)
          XRP(1)=X/W
          YRP(1)=Y/H
          IF (COUNT.EQ.0.) GOTO 115
          DO 114 J=1,ISUM
  114      UC(J)=UA(1)
          GO TO 108
  115      READ (INPUT,*) X,Y,U,COUNT
          WRITE (IOUTP,947) X,Y,U
          X=X/W
          Y=Y/H
          IF (ABS(X-XRP(I)).LT.0.00001) GOTO 116
          IJ=(I-1)*MYE+1
C
C
      CALL LAGR (YE,UC,MYE,IJ,YRP,UA,J)
      I=I+1
      XRP(I)=X
      J=0
  116      J=J+1
          YRP(J)=Y
```



```

UA(J)=U
IF (COUNT.EQ.0.) GO TO 115
IJ=(I-1)*MYE+1
CALL LAGR (YE,UC,MYE,IJ,YRP,UA,J)
IJ=1-IEND
DO 117 JJ=1,MYE
II=JJ-MYE
IJ=IJ+IEND
DO 118 J=1,I
II=II+MYE
118 UA(J)=UC(II)
117 CALL LAGR (XT,UD,IEND,IJ,XRP,UA,I)
IJ=0
DO 119 JJ=1,IEND
II=JJ-IEND
DO 119 J=1,MYE
IJ=IJ+1
II=II+IEND
UC(IJ)=UD(II)
119 CONTINUE

```

C  
C Write load characteristics and compute average pore pressure and  
C immediate settlements. rewind tape 1 for storage purposes.  
C

```

108 REWIND 1
C
WRITE (IOUTP,900)
WRITE (IOUTP,939) LIFT,TL(LIFT)
WRITE (IOUTP,916) A,B
WRITE (IOUTP,930) GLOAD,CLOAD,YWM,TGPHI,MINP
DO 120 I=1,MINP
120 WRITE (IOUTP,931) XINP(I),YINP(I)
WRITE (IOUTP,902)

```

C  
IF (IDEN(1)) 73,74,516  
74 IDEN(1)=MINP  
73 CALL PORE (XINP,YINP,IDEN(1),NS,XT,IEND,YE,MYE,UB,A,B)  
IF (HF.EQ.0.) GOTO 516  
IF (IPOR.EQ.1) GOTO 516

C  
C Find the horizontal distance to the point where the pore pressure is  
C 0.1% of the maximum pore pressure under the embankment. This is  
C considered as the drainage end in the hori direction.

```

CALL HDIST (UB,XT,IEND,ICV,CHIN,DXSQ,AAH,MHE,W,XET,IPOR,
* HF,MYE,POR)
516 IF (ISP.EQ.1) GO TO 510
WRITE (IOUTP,941) FSI,SPECS(LIFT),SPECU(LIFT),IEND
WRITE (IOUTP,960) TL(LIFT),LIFT,FS,FSI
WRITE (IOUTP,902)

```

C  
C Compute Immediate settlements, SETI, if B.NE.1 compute  
C pore pressures UAVED from UB, if IRP=0 or from UB+UC,  
C if IRP.NE.0, write information on tape 1.  
C

```

510 IF (B.NE.1.) GO TO 402
DO 403 I=1,IEND
403 SETI(I)=0.
GO TO 405
402 CALL SETL (UB,SETC,IEND,KKK,MYE,1.,FUP,FLO,KIAV)
AI=1./B

```

```

      CALL SETL (UB,SETT,IEND,KKK,MYE,AI,FUP,FLO,KIAV)
      DO 404 I=1,IEND
404    SETI(I)=SETT(I)-SETC(I)
405    II=0
      DO 121 I=1,IEND
      SETC(I)=0.
      SETT(I)=SETI(I)
      UAVE(I)=0.
      UAVED(I)=0.
      UAVEM(I)=0.
      WRITE (1) SETI(I),SETC(I),SETT(I),UAVE(I)
      DO 122 J=1,MYE
      II=II+1
      UD(II)=UB(II)+UC(II)
      UAVED(I)=UAVED(I)+UD(II)*SV(J)
      UM(II)=UB(II)/B+UC(II)
      UAVEM(I)=UAVEM(I)+UM(II)*SV(J)
      UC(II)=UB(II)
122    UB(II)=UD(II)
121    CONTINUE
C
C Determine soil parameters in a form suitable for the subroutine
C DISP. Only one OMEGA- and ONE PHI- element for the case of
C constant soil parameters and full saturation.
C
      if (IEND.GT.5) goto 1241
      CALL LAGR (XET,UE,N,1,XT,UAVEM,IEND)
      CALL LAGR (XET,UF,N,1,XT,UAVED,IEND)
      go to 1242
1241    call LINT (XET,UE,N,N,XT,UAVEM,IEND)
      call LINT (XET,UF,N,N,XT,UAVE,IEND)
1242    IF (IVAR.NE.0) GO TO 124
      PHI(1)=CV/DYSQ
      OMEGA(1)=0.
      IF (HF.GT.0.) OMEGA(1)=CH/DXSQ
      GOTO 123
124    KOUNT=1
      CALL COEF (UAVEM,UAVED,OMEGA,PHI,1,1,OMED,PHID,IEND)
      IF (HF.EQ.0.) GO TO 125
      CALL COEF (UE,UF,OMEGA,PHI,1,2,OMED,PHID,N)
125    KOUNT=0
C
C CONDITIONS IN THE CONSOLIDATION PROCESS.
C
123    CALL DISP (UB,5,OMEGA,PHI,0.,UAVE,1,MYE,IEND,XT,SV)
C
C SECOND OR FOLLOWING LOAD
C *****
C
C Read characteristics of next load depending on the value of
C LIFT+1.
C Define the index ISTAB.
C ISTAB=0 Determine the factor of safety.
C ISTAB=1 NO stability analysis. ISTAB is set equal to 1 if
C pore pressures at special points are to be computed
C ISP=1
C FSI=specified factor of safety for the LL-th load distribution.
C SPECS= specified fraction of the consolidation settlement.
C SPECU-- if an average degree of consol. of 0.95 due to the

```

C lift-th load is obtained at SPECU(LIFT)\*IEND points XT without  
C a sufficient factor of safety for the LL-th load the LIFT-th  
C load is taken to be the last load and NL is set NL=LIFT.  
C TMIN first stability analysis for the LL-th load will be  
C done.  
C for TD.GE.TMIN days after application of the LIFT-th load.  
C XC,YC =coord of the center of the first trial arc.  
C If IAB.NE.0 new pore pressure parameters A and B are input.

```

128   IF (LL.GT.NL) GOTO 129
      READ (INPUT,*) MINP,NS,IAB
      DO 130 I=1,MINP
130   READ (INPUT,*) XINP(I),YINP(I)
      IF (IAB.NE.0) READ (INPUT,*) A,B
      ISTAB=ISP
      IF (ISP.EQ.1) GO TO 518
      READ (INPUT,*) FSI,SPECS(LL),SPECU(LL),TMIN,XC,YC,ZZ
      CALL INIT (XINP,YINP,MINP,XC,YC,YY,ZZ,DMIN)
      GO TO 129
518   TSTEP=TL(LL)-TL(LIFT)
129   ITB=ITB+1
      IF (ITB.GT.ITBL) GO TO 200

```

C  
C Compute pore pressures at time T(IT). Determine variable soil  
C parameters. Compute consol. settlements. Perform stability  
C analysis.

```

      TD=TB(ITB)
      IT=IT+1
      IF (ISP.EQ.0) GOTO 131
      IF (LL.GT.NL) GO TO 131
      IF (TSTEP.LT.TD) TD=TSTEP
131   T(IT)=TL(LIFT)+TD
      CALL DISP (UB,2,OMEGA,PHI,TD,UAVE,LIFT,MYE,IEND,XT,SV)

```

C  
C Vector UB contains the pore pressures at time T(IT). Vector UVAE  
C contains the average pore pressures as computed from UB.  
C Vector UA contains the dissipated pore pressures up to time T(IT).

```

      IF (IVAR.EQ.0) GO TO 232
      if (IEND.GT.5) go to 2321
      CALL LAGR (XET,UF,N,1,XT,UAVE,IEND)
      go to 2322
2321  call LINT (XET,UF,N,N,XT,UAVE,IEND)
2322  CALL COEF (UAVEM,UAVE,OMEGA,PHI,3,1,OMED,PHID,IEND)
      CALL COEF (UE,UF,OMEGA,PHI,3,2,OMED,PHID,N)
      CALL DISP (UB,3,OMED,PHID,TD,UAVE,LIFT,MYE,IEND,XT,SV)
232   IF (LL.GT.NL) GO TO 133
      IF (ISTAB.EQ.1) GOTO 133
      IF (TD.LT.TMIN) GO TO 133
      DO 72 J=1,ISUM
      UA(J)=UM(J)-UB(J)
72   CONTINUE
      CALL GAIN (UA,R,SU,MYE,MXT,MXE,MX,NIM,CO,CP,0)
      CALL STAB (XC,YC,RR,XINP,YINP,MINP,MX,MYE,SU,FS,DMAX,DMIN,YY)
      IF (FS.LT.FSI) GOTO 75
      ISTAB=1
      WRITE (IOUTP,902)
75   WRITE (IOUTP,942) T(IT),LL,FS,FSI
      WRITE (IOUTP,842) XC,YC,RR

```

C  
C Compute settlements and average degrees of consolidation.  
C Count at how many points XT the degree of consolidation as  
C compared to the pore pressures at the time of the last load  
C application is greater than 95%.

C  
133 UCHEK=0.  
DO 132 J=1,ISUM  
UA(J)=UD(J)-UB(J)  
132 CONTINUE  
CALL SETL (UA,SETC,IEND,KKK,MYE,1.,FUP,FLO,KIAV)  
DO 134 I=1,IEND  
SETT(I)=SETI(I)+SETC(I)  
IF (UAVE(I).LT.(0.05\*UAVED(I))) UCHEK=UCHEK+1.  
UAVE(I)=(UAVED(I)-UAVE(I))/UAVR(I)  
WRITE (1) SETI(I),SETC(I),SETT(I),UAVE(I)  
134 CONTINUE

C  
C In the following checks are made for the no. of lift, whether  
C the FS is sufficient for the next lift, whether a specified amount  
C of settlement at point XT(1) has already occurred, whether the  
C available construction time TA has been passed, and whether an  
C average degree of consol. relative to the pore pressures at the time  
C of load application of 95% has been reached at .GE.SPECU(LIFT)\*IEND  
C points XT

C  
IF (LIFT.EQ.NL) GOTO 129  
IF (ISP.EQ.0) GO TO 135  
IF (TD.EQ.TSTEP) go to 137  
GO TO 129  
135 IF (ISTAB.EQ.0) GO TO 138  
IF (SETC(1).GT.SPECS(LIFT)\*SETRC(1)) GO TO 137  
138 IF (T(IT).GT.TA) GO TO 139  
IF (UCHEK.LT.AIEND\*SPECU(LIFT)) GO TO 129  
NL=LIFT  
III=UCHEK+0.1  
WRITE (IOUTP,948) III,IEND,TL(LIFT),LIFT  
GO TO 129

C  
139 NL=LIFT

This page is left blank intentionally.

```
WRITE (IOUTP,949) FS,SETC(1),T(IT),TA,LIFT
GO TO 129
```

C

```
137  LIFT=LL
      LL=LIFT+1
      ITB=1
      TL(LIFT)=T(IT)
      IT=IT+1
      T(IT)=TL(LIFT)
      WRITE (IOUTP,900)
      WRITE (IOUTP,939) LIFT,TL(LIFT)
      WRITE (IOUTP,916) A,B
      WRITE (IOUTP,930) GLOAD,CLOAD,YWM,TOPHI,MINP
      DO 140 I=1,MINP
140  WRITE (IOUTP,931) XINP(I),YINP(I)
      WRITE (IOUTP,902)
```

C

C compute pore pressures due to new load. Compute imm. settlements,  
C SETI, if B.NE.1. Note that the consol. settlements, SETC and the  
C ave. degree of consol are the same as computed at time  
C T(IT-1)=TL(LIFT).

C

C Note pore pressures due to the load addition are neglected in  
C the computation of imm. settlements. Since zero swelling is  
C assumed, negative pore pressures after load application are  
C set equal to zero. This means that negative pore pressures due  
C to load removal are considered only in a magnitude equal to  
C the not dissipated pore pressures just before load removal.

C

```
      IF (IDEN(LIFT).EQ.0) GO TO 76
      DO 77 I=1,ISUM
      UA(I)=UU(I)
77  CONTINUE
      GO TO 78
76  CALL PORE (XINP,YINP,MINP,NS,XT,IEND,YE,MYE,UA,A,B)
78  IF (ISP.EQ.1) GO TO 511
      WRITE (IOUTP,941) FSI,SPECS(LIFT),SPECU(LIFT),IEND
      WRITE (IOUTP,960) TL(LIFT),LIFT,FS,FSI
      WRITE (IOUTP,902)
```

```
511  IF ((1.-B).LT.0.00001) goto 143
      CALL SETL (UA,SETRI,IEND,KKK,MYE,1.,FUP,FLO,KIAV)
      AI=1./B
      CALL SETL (UA,SETT,IEND,KKK,MYE,AI,FUP,FLO,KIAV)
      do 141 I=1,IEND
      SETRI(I)=SETT(I)-SETRI(I)
      IF (SETRI(I).GT.SETI(I)) SETI(I)=SETRI(I)
      SETT(I)=SETI(I)+SETC(I)
141  CONTINUE
```

C

```
143  II=0
      DO 144 I=1,IEND
      WRITE (1) SETI(I),SETC(I),SETT(I),UAVE(I)
      UAVE(I)=0.
      UAVED(I)=0.
      UAVEM(I)=0.
      DO 144 J=1,MYE
      II=II+1
      UT=UB(II)+UA(II)-UC(II)
      IF (UT.LT.0.) UT=0.
      UAVE(I)=UAVE(I)+UT*SV(J)
```

```

UB(II)=UT-UB(II)
UC(II)=UA(II)
UD(II)=UD(II)+UB(II)
UAVED(I)=UAVED(I)+UD(II)*SV(J)
UM(II)=UD(II)+(1./B-1.)*UA(II)
UAVEM(I)=UAVEM(I)+UM(II)*SV(J)
44  CONTINUE
    LLL=LIFT-1
    CALL DISP (UB,3,OMEGA,PHI,TD,UAVE,LLL,MYE,IEND,XT,SV)
    IF (IVAR.EQ.0) GO TO 244
    if (IEND.GT.5) goto 1444
    CALL LAGR (XET,UF,N,1,XT,UAVE,IEND)
    CALL LAGR (XET,UE,N,1,XT,UAVEM,IEND)
    goto 1445
444  call LINT (XET,UF,N,N,XT,UAVE,IEND)
    call LINT (XET,UE,N,N,XT,UAVEM,IEND)
445  CALL COEF (UAVEM,UAVE,OMEGA,PHI,1,1,OMED,PHID,IEND)
    CALL CDEF (UE,UF,OMEGA,PHI,1,2,OMED,PHID,N)
244  CALL DISP (UB,1,OMEGA,PHI,0.,UAVE,LIFT,MYE,IEND,XT,SV)
    GO TO 128

```

```

200  rewind 1
    write(IDUTP,5013)
5013  format ('Reached end of file')
    REWIND 2

```

# OUTPUT OF RESULTS

\*\*\*\*\*

Write title for output of results of the consol. process.

```

    WRITE (IDUTP,901)
    WRITE (IDUTP,950)
    IF (ISP.EQ.1) GO TO 217
    DO 218 I=1,JND
    K=JSP(I)
18   XRP(I)=W*XE(K)

```

Determine indices MXS(I), I=1,NIM and matrix RSP which is a sub matrix of matrix R. Matrix RSP is needed when interpolation between points XT is done to get the information required at points XRP/W.

```

    IRE=0
    IRS=0
    K=1
    MMM=MXE(1)
    MT=MXT(1)
    DO 210 JJ=1,NIM
210  MXS(JJ)=0

    JJ=1
    DO 211 I=1,MX
    IF (JSP(K).EQ.1) GO TO 214
    GO TO 215
214  DO 212 J=1,MT
    IRS=IRS+1
    IRE=IRE+1
212  RSP(IRS)=R(IRE)

```

```

C      MXS(JJ)=MXS(JJ)+1
      IF (K.EQ.JND) GOTO 213
      K=K+1
215    IF (MMM.NE.1) GO TO 211
      JJ=JJ+1
      MT=MXT(JJ)
      MMM=MMM+MXE(JJ)
211    CONTINUE
C
C
C CASE THAT ISP=1
C
217    JND=IEND
      DO 219 I=1,JND
219    XRP(I)=W*XT(I)
C
213    WRITE (IOUTP,951) (XRP(I),I=1,JND)
      WRITE (IOUTP,900)
      DO 250 I=1,JND
250    XRP(I)=XRP(I)/W
C
C
      MMM=2
      IF (B.NE.1.) MMM=4
      MT=MMM*JND
C
C Read UAVE,SETC and SETT, given at points XT from TAPE 1. if
C ISP=1, this is the information to be output. IF ISP=0,
C perform interpolation using matrix RSP. Outpiy the
C information and store it on TAPE 2 for later plots for times
C T(J), J=1,IT. Use UA and UB for temporary storage.
C
      DO 220 J=1,IT
      II=1
      DO 221 I=1,IEND
      READ (1) AI,UA(II+1),AA,UA(II)
      IF ((1.-B).LT.0.00001) GOTO 224
      UA(II+2)=AI
      UA(II+3)=AA
224    II=II+MMM
221    CONTINUE
      IF (ISP.EQ.1) GO TO 225
C
C Interpolation for points XRP(I)/W by means of matrix multi-
C plication. Information for points XT is in UA. Interpolation
C for points XRP(I)/W is stored in UB
C
      IUBE=0
      IUND=0
      IRND=0
      DO 216 JJ=1,NIM
      IUBS=IUBE+1
      IUBE=IUBE+MMM*MXT(JJ)
      IF (MXS(JJ).EQ.0) GO TO 216
      IUST=IUND+1
      IUND=IUND+MMM*MXS(JJ)
      IRST=IRND+1
      IRND=IRND+MXT(JJ)*MXS(JJ)
      CALL MPRD (UA,RSP,UB,MMM,MXT(JJ),MXS(JJ),IUBS,IRST,IUST)

```



216 CONTINUE  
GO TO 226

DEFINE UB FOR CASE OF ISP=1

225 DO 222 I=1, MT  
222 UB(I)=UA(I)  
  
226 IF (J.EQ.1) GO TO 227  
IF (T(J).NE.T(J-1)) GO TO 228  
227 WRITE (IDOUTP,952) T(J)  
228 WRITE (IDOUTP,953) T(J)  
  
DO 223 K=1, MMM  
WRITE (IDOUTP,951) (UB(I), I=K, MT, MMM)  
223 CONTINUE

WRITE (2) (UB(I), I=1, MT)

220 CONTINUE

REWIND 1  
REWIND 2

PLOTTING ROUTINE

\*\*\*\*\*

KEND=T(IT)/7. +1.001  
IF (LND.GT.KEND) LND=KEND

Compute the reference settlement for points XRP from total settlements SETRT at points XT.

IF(ISP.EQ.0) GO TO 297  
DO 298 I=1, IEND  
298 SETR(I)=SETRT(I)  
GO TO 299  
  
297 IUBE=0  
IUND=0  
IRND=0  
DO 406 I=1, NIM  
IUBS=IUBE+1  
IUBE=IUBE+MXT(I)  
IF (MXS(I).EQ.0) GO TO 406  
IUST=IUND+1  
IUND=IUND+MXS(I)  
IRST=IRND+1  
IRND=IRND+MXT(I)\*MXS(I)  
CALL MPRD (SETRT, RSP, SETR, 1, MXT(I), MXS(I), IUBS, IRST, IUST)  
06 CONTINUE  
  
99 DO 300 J=1, JND  
JS=(J-1)\*MMM+1

WRITE TITLE FOR J-TH PLOT

```
X=XRP(J)*W
WRITE (IOUTP,901)
WRITE (IOUTP,954) X,SETR(J),SYMB(1),SYMB(2)
IF (MMM.EQ.4) WRITE (IOUTP,955) SYMB(3),SYMB(4)
WRITE (IOUTP,900)

C
    REWIND 2
    READ (2) (UB(I), I=1,MT)

C
C GENERATE FIRST LIN TO BE PRINTED
C
    LOUT=T(1)/7.+0.1
    JT=2
    K=T(2)/7.+0.1
    DO 301 I=1,76
301    ROW(I)=STAR
    DO 302 I=6,71,5
302    ROW(I)=GRID

C
    JJ=JS
    II=50.*UB(JJ)+1.5
    ROW(II)=SYMB(1)

C
    DO 303 I=2,MMM
    JJ=JJ+1
    II=50.*UB(JJ)/SETR(J)+1.5
303    ROW(II)=SYMB(I)

C
C Write first line and clear ROW(I) afterwards.
C
    WRITE (IOUTP,957)
    WRITE(IOUTP,956) LOUT,(ROW(I), I=1,76)
    DO 304 I=2,75
304    ROW(I)=BLANK
    ROW(1)=STAR
    ROW(76)=STAR
    MK=MMM

C
C Determine the following to be printed.
C
    DO 306 L=2,LND
    LOUT=LOUT+1
    IF(K.EQ.LOUT) GO TO 305
    WRITE (IOUTP,956) LOUT,(ROW(I), I=1,76)
    GO TO 306
305    JT=JT+1
    IF (JT.GT.IT) JT=1
    K=T(JT)/7.+0.1

C
C Read data from TAPE and determine symbols to be printed
C
309    READ (2) (UB(I), I=1,MT)
    JJ=JS
    IKK=MK-MMM+1
    II=50.*UB(JJ)+1.5
    ROW(II)=SYMB(1)
    KK(IKK)=II

C
    DO 307 I=2,MMM
    JJ=JJ+1
```

```

IKK=IKK+1
II=50.*UB(JJ)/SETR(J)+1.5
ROW(II)=SYMB(I)
KK(IKK)=II
CONTINUE

```

```

307
IF (K.NE.LOUT) GO TO 310
JT=JT+1
K=T(JT)/7.+0.1
MK=MK+MMM
GO TO 309

```

Print the L-th line and BLANK out the second through 75-th element.

```

310 WRITE (IOUTP,956) LOUT,(ROW(I),I=1,76)
DO 308 I=1,MK
II=KK(I)
308 ROW(II)=BLANK
ROW(1)=STAR
ROW(76)=STAR
MK=MMM
306 CONTINUE

```

Generate and print last line

```

DO 311 I=1,76
311 ROW(I)=STAR
DO 312 I=6,76,5
312 ROW(I)=GRID
LOUT=LOUT+1
WRITE (IOUTP,956) LOUT,(ROW(I),I=1,76)
300 CONTINUE

```

```

IF (NL.NE.NLS) GOTO 10000
GO TO 100

```

# FORMAT STATEMENTS

\*\*\*\*\*

```

:91 FORMAT (15I4)
:92 FORMAT (8F8.3)
:93 FORMAT (4E10.5)
:94 FORMAT (7A1)

```

```

000 FORMAT (////////)
001 FORMAT (1H1)
002 FORMAT (//)
003 FORMAT (1H ,25x, '*****', /

```

```

1 1H ,25x, '*' *, /
2 1H ,25x, '*' CONSOLIDATION PROBLEM *, /
3 1H ,25x, '*' *, /
4 1H ,25x, '*' STEP LOADING & SURCHARGE *, /
5 1H ,25x, '*****')

```

```

004 FORMAT (1H ,10x, 'THE PORE WATER PRESSURES ARE COMPUTED AT')
005 FORMAT (1H ,10x, ' YE/H ',5f10.3)
006 FORMAT (1H ,10x, ' XT/W ',5f10.3)
007 FORMAT (1H0,10x, 'THE PORE PRESSURES ARE INTERPOLATED AT')
008 FORMAT (1H ,10x, ' XE/W= ',5f10.3)
009 FORMAT (1H ,10x, 'ASSUMING COLLOCATION POLYNOMIALS OF DEGREE ')
010 FORMAT (1H ,10x, I1, ' BETWEEN THE LIMITS ',f8.3, ' AND ',f8.3)

```

```

911  FORMAT (1H0,10x,'HORIZONTAL PORE PRESSURES ARE COMPUTED AT')
912  FORMAT (1H ,10x,' X= ',f10.3)
913  FORMAT (1H0,10X,'THE SUBSOIL IS DESCRIBED BY THE FOLLOWING'//
1    11x,'parameters which are given for the upper layer'//
2    1H ,10X,'IN CASE OF STRATIFICATION'//)

C
C
914  FORMAT (1H ,10x,'TOTAL THICKNESS ', 'H=',f8.3,' FEET '//
1    1H ,10x,'reference for X-COORD W = ',f8.3,' FEET')
915  FORMAT (1H0,10X,'LAYER INTERFACE IS ',f8.3,' FT BELOW SURFACE',//
2    1H ,10x,'LOWER/UPPER PERMEABILITY, RK= ',f8.3,/,
3    1H ,10x,'LOWER/UPPER COEF. OF CONSOLIDATION, RC= ',f8.3/,
4    1H ,10x,'LOWER/UPPER INITIAL VOID RATIO, REO= ',f8.3)
815  FORMAT (1H ,10x,'LOWER/UPPER COEF. OF COMPRESS, RAV= ',f8.3)
715  FORMAT (1H ,10x,'LOWER/UPPER COMPRESSION INDEX, RCC= ',f8.3/
1    1H ,10x,'LOWER/UPPER RECOMPRESSION INDEX RROCL = ',f8.3)
916  FORMAT (1H ,10X,'SKEMPTON PORE PRESSURE COEFFICIENTS ARE',/
1    1H ,10X,' A= ',f5.2,' AND B= ',f5.2,/)
917  FORMAT (1H ,10X,'DEGREE OF SATURATION IS S= ',f5.3,/
1    1H ,10X,'HENRY-S CONSTANT OF GAS SOLUBILITY HC = ',f7.3,/
2    1H ,10x,'INITL PORE GAS PRESSURE IS PU= ',E12.4,' PSF')
918  FORMAT (1H ,10X,'INITIAL VOID RATIO = ',f6.3)
818  FORMAT (1H ,10X,'INITIAL COEFF. OF COMPRESSIBILITY IS AVO= ',/
1    1H ,10x,E12.4,' FT*FT /LB. ')
919  FORMAT (1H ,10X,'THE COMPRESSION INDEX IS = ',E12.4,/
1    1H ,10X,'RECOMPRESSION INDEX/CC ROC= ',f8.3)
819  FORMAT (1H ,10X,'INITIAL EFFECTIVE P AND PRECOMPRESSION',/
1    1H ,10X,'STRESSES PC AS USED IN THE COMPUTATIONS',/
2    1H ,10X,'Y IN FT',3X,'P IN PSF',4X,'PC IN PSF')
719  FORMAT (1H ,10X,f9.3,2f13.2)
619  FORMAT (1H0,10X,'NOTE -P(1) AND PC(1) MAY HAVE BEEN CHANGED',/
1    1H ,10X,'as compared to input values to avoid over flow')
920  FORMAT (1H ,10X,'THE INITIAL PERMEABILITIES ARE IN',/
1    1H ,10x,'VERTICAL DIRN. KVD= ',E12.4,' FT/DAY',/
2    1H ,10x,'HORIZONTAL DIRN KHO= ',E12.4,' FT/DAY')
820  FORMAT (1H ,10X,'THE FOLLOWING COEFF. OF CONSOLIDATION',/
1    1H , 10X,'ARE IN PUT AT SPECIFIED EFFECTIVE STRESSES',/
2    1H0,3x,'EFF-STRESS(PSF)',2x,'V-COEF(FT*FT/DAY)',
3    2x,'EFF-STRES(PSF)',2x,'H-COEF(FT*FT/DAY)')
720  FORMAT (1H ,7x,f10.2,7x,E12.4,7x,f10.2,7x,E12.4)
921  FORMAT (1H ,10X,'THE SLOPES OF THE E Vs LOG(K)-CURVES ARE',/
1    1H ,10x,'IN VERTICAL DIRN, SKV= ',f8.3,/
2    1H ,10x,'IN HORI. DIRN, SKH= ',f8.3)
922  FORMAT (1H0,10X,'THE DRAINAGE CONDITIONS ARE')
926  FORMAT (1H ,10X,'IMPEDED DRAINAGE AT THE BOTTOM WITH',/
1    1H ,10X,'VERT. PERM/VERT. IMPEDED PERM RKV= ',f5.2,/
2    1H ,10X,'THICKNESS OF IMPEDED LAYER, HI= ',f8.3,'FT')
927  FORMAT (1H ,10X,'FREE DRAINAGE AT THE BOTTOM')
928  FORMAT (1H ,10X,'NO DRAINAGE AT THE BOTTOM')
930  FORMAT (1H ,10X,'THE LOAD CHARACTERISTICS ARE GIVEN BY',/
1    1H ,10X,'THE UNIT WEIGHT GLOAD= ',f7.2,' PCF',/
2    1H ,10X,'THE COHESION , CLOAD= ',f8.2,' PSF',/
3    1H ,10x,'THICKNESS OF THE DRAINAGE BLANKET YWM=',f6.2,'FT',/
4    1H ,10x,'THE TANGENT OF THE ANGLE ',/
5    1H ,10X,'OF INTERNAL FRICTION TGPHI= ',f7.4,/
6    1H ,10X,'MINP= ',I3,' COOR POINTS XINP/YINP')
931  FORMAT (1H ,20X,f10.2,' FEET ',f10.2,' FEET')
932  format (1H ,10X,'THE AVERAGE PORE PRESSURES, UAVER(I)',/
1    1H ,10X,'THE CONSOLIDATION SETTLEMENTS, SETRC(I) AND THE',
2    1H ,10X,'TOTAL SETTLEMENTS, SETRT(I), AT XT(I) ARE',/

```

```

3      1H , 10X, 'XT FEET', 4X, 'UAVE (PSF)', 3X, 'SETRC', /
4      ' FEET', 3X, 'SETRT FEET')
933    FORMAT (1H , 10X, F7.2, 4X, F12.2, 4X, F9.3, 3X, F9.3)
934    FORMAT (1H , 10X, 'COEFF OF CONSOL. VERT FLOW IS CV= ', /
1      1H , 10X, E12.4, ' FEET**2/DAY', /
2      1H , 10X, 'COEF. OF CONSOL. HORI. FLOW IS CH= ', /
3      1H , 10X, E12.4, ' FT**2/DAY')
935    FORMAT (1H, 10X, 'REFERENCE LOAD', /
1      1H , 10X, '*****')
936    FORMAT (1H , 10X, 'THE NUMBER OF LIFTS IS NL= ', I3)
937    FORMAT (1H , 10X, 'SINCE ISP=1 TIMES OF LOAD APPLICATION', /
1      1H , 10X, 'ARE INPUT TO BE', ///)
938    FORMAT (1H , 10X, 'TL(', I2, ') = ', F6.0, ' DAYS')
939    FORMAT (1H, 10X, 'LOAD NO ', I3, ' APPLIED AT TL= ', F6.0, 'DAYS', /
1      1H , 10X, '*****')
940    FORMAT (1H, 10X, 'THE AVAILABLE CONSTRUCTION TIME IS TA= ', /
1      1H , 10X, F6.0, ' DAYS. TA IS NOT NEEDED IF NL=1')
840    FORMAT (1H , 10X, 'PARAMETERS USED IN THE STABILITY ANALYSIS', /
1      1H, 10X, 'DMAX= ', F8.3, 5X, 'DMIN= ', F8.3, /
2      1H , 10X, 'NARC= ', I4, 'NRAD= ', I4, /
3      1H , 10X, 'DMAX, DMIN ARE THE MAX AND MIN STEP SIZES', /
4      1H , 10X, 'USED IN THE SEARCH PROCEDURE', /
5      1H , 10X, 'NARC=ONE- HALF THE NUMBER OF SUB ARCS', /
6      1H , 10X, 'NRAD=NUMBER', 'OF RADII USED FOR EACH TRIAL CENTER', /
7      1H , 10X, 'OF ARCS')
941    FORMAT (1H , 10X, 'THE REQUIRED SAFETY FACTOR IS FSI= ', F6.3, /
1      1H , 10X, 'THE SPECIFIED PORTION OF SETTLEMENT IS', /
NL 10 1H , 10X, 'CO. J', '1H , 10X, 'EQUAL TO', F6.3, /
3      1H , 10X, ' IF 95% OF THE AVE PORE PRESSURE', /
4      1H , 10X, 'AT THE TIME OF APPLICATION OF THIS LOAD', /
5      1H , 10X, 'HAVE DISSIPATED AT ', F6.4, '*', I2, 'POINTS XT', /
6      1H , 10X, 'THIS LIFT IS ASSUMED TO BE THE LAST ONE', /)
942    FORMAT (1H, 10X, 'THE FACTOR OF SAFETY AT TIME T= ', F6.0, /
1      1H , 10X, 'DAYS FOR LIFT ', I3, ' IS FS= ', F6.3, /
2      1H , 10X, 'AS COMPARED TO THE REGU. FSI= ', F6.3)
842    FORMAT (1H , 10X, 'FS HAS BEEN OBTAINED FOR THE ARC WITH', /
1      1H , 10X, 'X=', F8.2, ' Y= ', F8.2, ' RADIUS= ', F8.2, ' IN FT')
943    FORMAT (1H , 10X, 'SINCE FS. LT. FSI, TERMINATE THE PROGRAM')
944    FORMAT (1H , 10X, 'RESIDUAL PORE PRESSURES AS INPUT IN PSF', /
1      1H , 10X, 'YE(I)/H=', I2X, 11F9.3)
945    FORMAT (1H , 'X(', I2, ')/W= ', F8.3, 4X, 11F9.3)
946    FORMAT (1H, 10X, 'RESIDUAL PORE PRESSURES ARE IN PUT AS', /
1      1H , 10X, 3X, 'X (FEET)', 3X, 'Y (FEET)', 3X, 'UC (PSF)')
947    FORMAT (1H , 10X, 3F12.3)
948    FORMAT (///, 1H , 10X, 'AT ', I3, ' OUT OF ', I3, ' POINTS XT', /
1      1H , 10X, 'AN AVE DEGREE OF CONSOL. OF 95%', /
2      1H , 10X, 'HAS COMPARED TO PORE PRESSURES AT THE TIME T= ', /
3      1H , 10X, F6.0, ' DAYS OF LAST LOAD APPLICATION', /
4      1H, 10X, '*** THIS LIFT NO. ', I3, /
5      1H , 10X, 'IS THEREFORE CONSIDERED TO BE THE LAST ONE***', ///)
949    FORMAT (///, 1H , 10X, 'EITHER THE FACTOR OF SAFETY, FS= ', F6.3, /
1      1H , 10X, 'AND/OR THE SETTLEMENT, SETC(1)= ', F6.3, 'FEET', /
2      1H , 10X, 'ARE LESS THAN SPECIFIED AT TIME T= ', F6.0, 'DAYS', /
3      1H , 10X, 'WHICH IS GREATER THAN TA= ', F6.0, 'DAYS', /
4      1H, 10X, '*** THIS LIFT NO ', I3, ' IS, THEREFORE', /
5      1H , 10X, 'CONSIDERED TO BE THE LAST ONE***', ///)
950    FORMAT (1H, 10X, 'THE CONSOL. PROCESS', /
1      1H , 10X, '*****', ///),
2      1H , 10X, 'THE FOLLOWING INFORMATION IS OUT PUT', /
3      1H, 10X, 'UAVE(X(1)), UAVE(X(2)), .....', /

```

```

4      1H ,10X, '= AVER DEGREES OF CONSOL. WITH RESPECT TP REF. LC
5      1H ,10X, 'SETC(X(1)),SETC(X(2)),.....', /
6      1H ,10X, '= CONSOL. SETTLEMENTS', /
7      1H ,10X, 'SETI(X(1)),SETI(X(2)),.....', /
8      1H ,10X, '= IMMEDIATE SETTLEMENTS', /
9      1H ,10X, 'SETT(X(1)),SETT(X(2)),.....', /
*      1H ,10X, '= CONSOLI. + IMMEDIATE SETTLEMENTS', /
1      1H ,10X, 'LAST TWO LINE ARE ONLY OUT PUT', /
2      1H ,10X, 'IF SOIL IS PARTIALLY SATURATED (B.NE.1.)', /
3      1H ,10X, 'THE POINTS X(I) IN FEET ARE AS FOLLOWS', /
951    format (2x,10F8.3)
952    FORMAT (/,1H ,10X, 'T= ',F6.0, /
1      1H ,10X, 'DAYS IS THE TIME OF LOAD APPLICATION', /)
953    FORMAT (/,1H ,10X, 'T= ',F6.0, 'DAYS', /)
954    FORMAT (1H ,10X, 'AVE DEGREE OF CONSOL. AND SETTLEMENT', /
1      1H ,10X, 'CURVES FOR POINT X= ',F8.2, 'FEET FROM CENTER LINE
2      1H ,10X, 'INTERVAL BETWEEN 2 GRID LINES.EG.10X', /
3      1H ,10X, 'ABSCISSA NUMBERS GIVE THE TIME IN WKS', /
4      1H ,10X, 'THE TOTAL SETTL DUE TO REFERENCE LOAD IS', /
5      1H ,10X, E10.3, ' FEET', /
6      1H ,10X, A1, ' -CUREV= AVE. DEGREE OF CONSOL. ', /
7      1H ,10X, 'RELATIVE TO THE PORE PRESS DUE TO REF LOAD', /
8      1H ,10X, A1, ' -CURVE=CONSOL. SETT. IN % OF', /
9      1H ,10X, 'REF. SETTLEMENT')
955    FORMAT (1H ,10X, A1, ' -CURVE=IMMEDIATE SETTLEMENTS IN % OF', /
1      1H ,10X, 'THE REFERENCE SETTLEMENTS', /,
2      1H ,10X, A1, ' -CURVE=TOTAL SETTLEMENTS IN % OF', /,
3      1H ,10X, 'THE REFERENCE EHSETTLEMENT', /)
956    format (1H ,13,76A1)
957    FORMAT (1H#,2X, '0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 ',
1      '0.9 1.0 1.1 1.2 1.3 1.4 1.5', /)
960    FORMAT (1H ,10X, 'THE FACTOR OF SAFETY AT TIME T= ',F6.0, /,
1      1H ,10X, 'DAYS FOR LIFT', I3, 'WAS .GE. FS= ',F6.3, /,
2      1H ,10X, 'AS COMPARED TO THE REGU. FSI= ',F6.3)
962    format (1H ,20x, f8.3, 12x, f8.3, 12x, f8.3)
194    format (7A1)
961    format (1H ,10x, 'THE SHEAR STRENGTH CHARACTERISTICS OF', /,
1      1H ,10X, 'THE SUB SOIL AS USED IN THE STABILITY ANALYSIS ARE
2      1H ,15x, 'DEPTH (FT)', 5x, 'COHESION (PSF)', 5x, 'P-RATIO')
10000  END
      subroutine LINT (X,Y,N1,M,XX,YY,N)
      dimension X(1),Y(1),XX(1),YY(1)
C This subroutine interpolates the values of function Y(X)
C from the known YY(XX) by use of the linear interpolation.
C or extrapolation.
C
      II=0
      JJ=0
      NN=M-N1+1
      do 20 I=NN,M
        II=II+1
        J=1
C Extrapolation is used if X(II).GT.XX(N)
      if (X(II).LT.XX(N)) go to 31
      Y(I)=YY(N)+(YY(N)-YY(N-1))*(X(II)-X(N))/(XX(N)-XX(N-1))
      go to 20
31     if (X(II).GT.XX(1)) go to 32
C Extrapolation is used if X(II).LT.XX(1)
      1111=2
      Y(I)=YY(1)-(YY(1111)-YY(1))*(XX(1)-X(II))/(XX(1111)-XX(1))

```

```

      goto 20
25  J=J+1
32  if (X(II).GT.XX(J)) go to 25
C Interpolation is used if XX(1).LT.X(II).LT.XX(N)
C If X(II) is very close to XX(J) then Y(I)=YY(J)
      if (ABS(X(II)-XX(J)).GT.0.00000001) go to 28
      Y(I)=YY(J)
      go to 20
28  XY1=XX(J-1)
      YY1=YY(J-1)
      Y(I)=YY1+(X(II)-XY1)*(YY(J)-YY1)/(XX(J)-XY1)
20  continue
      return
      end
C BEGIN SUBROUTINE INTEG
C
      SUBROUTINE INTEG (ETA,XI,B,AR)
C This subroutine computes the values of the stress integrals if
C the integration variable becomes larger than 12.
C
      DIMENSION AR(7)
C
      COMMON/ POAPI/ ALPHA(30),L
C
      PI=3.14159265358979
      ETAP=1.+ETA
      ETAM=1.-ETA
C
      DO 1 I=1,7
      AR(I)=0.
C
      DO 2 I=1,L
      pq=1./10000000000000000.
      AMX=ALPHA(I)-XI
      IF (ABS(AMX).LT.pq) GO TO 3
      AR(1)=AR(1)+PI-ATAN(ETAM/AMX)-ATAN(ETAP/AMX)
      IF (AMX.LT.0.) AR(1)=AR(1)-2.*PI
3     APX=ALPHA(I)+XI
      IF (ABS(APX).LT.pq) GO TO 4
      AR(1)=AR(1)+PI-ATAN(ETAM/APX)-ATAN(ETAP/APX)
      IF (APX.LT.0.) AR(1)=AR(1)-2.*PI
4     SIAMX=SIN(AMX*B)
C
      COAMX=COS(AMX*B)
      SIAPX=SIN(APX*B)
      COAPX=COS(APX*B)
C
      DPM=1./((ETAP*ETAP+AMX*AMX)
      DPP=1./((ETAP*ETAP+APX*APX)
      DMM=1./((ETAM*ETAM+AMX*AMX)
      DMP=1./((ETAM*ETAM+APX*APX)
C
      SM1=DPM*(ETAP*SIAMX+AMX*COAMX)
      CM1=DPM*(ETAP*COAMX-AMX*SIAMX)
      SP1=DPP*(ETAP*SIAPX+APX*COAPX)
      CP1=DPP*(ETAP*COAPX-APX*SIAPX)
C
      SM2=DMM*(ETAM*SIAMX+AMX*COAMX)
      CM2=DMM*(ETAM*COAMX-AMX*SIAMX)

```

```
SP2=DMP*(ETAM*SIAPX+APX*COAPX)
CP2=DMP*(ETAM*COAPX-APX*SIAPX)
```

C

```
AR(2)=AR(2)+SM2+SP2
AR(3)=AR(3)+SM1+SP1
AR(4)=AR(4)+DPM*(ETAP*SM1+AMX*CM1)+DPP*(ETAP*SP1+APX*CP1)
AR(5)=AR(5)+CM2-CP2
AR(6)=AR(6)+CM1-CP1
AR(7)=AR(7)+DPM*(ETAP*CM1-AMX*SM1)+DPP*(APX*SP1-ETAP*CP1)
```

2

```
CONTINUE
EXAP=EXP(-ETAP*B)/2.
EXAM=EXP(-ETAM*B)/2.
```

C

```
AR(1)=AR(1)/2.
AR(2)=EXAM*AR(2)*ETAM
AR(3)=EXAP*AR(3)
AR(4)=(EXAP*AR(4)+B*AR(3))*2.*ETA
AR(5)=EXAM*AR(5)*ETAM
AR(6)=EXAP*AR(6)
AR(7)=(EXAP*AR(7)+B*AR(6))*2.*ETA
AR(6)=AR(6)*ETAM
```

C

```
RETURN
END
```

C

C END OF SUBROUTINE INTEG

```
SUBROUTINE COEF (UAVD,UAVE,OMEGA,PHI,LI,IL,OMED,PHID,NN)
```

C

C This subroutine determines the soil parameters for the case that  
C they are variable.

C If LI=3, the difference between the old and the new parameters  
C PHI and OMEGA are also computed and stored in PHID and OMED, resp.

C

```
DIMENSION UAVD(1),UAVE(1),OMEGA(1),PHI(1),OMED(1),PHID(1)
DIMENSION SVM(12),P(11),PC(11),PLOG(11),AA(1),BB(1)
```

C

```
COMMON/ SACSE/ ROC,ROCL,SVM,P,PC,PLOG,PD,PCD,IAV,IK,ISAT,AAV,AAH
COMMON/ SAC01/ AVD,KVD,KHD,EDPUS,PU,SKHM,SKVM,CCC,NNN,ICDEF
COMMON/ SAC02/ PCV(10),CVIN(10),PCR(10),CHIN(10),ICV,KOUNT,HF
```

C

```
REAL K,KD,KV,KH,KVD,KHD
```

C

C Statement functions for the computation of the coeff. of  
C permeability. CONK is used, when K is variable and AV is const.  
C VARK is used, when K and AV are variable. PSI computes the  
C parameters to be returned to the calling program.

C

```
CONK(KD,SKM)=KD*EXP(-SKM*DISU)
VARK(KD,SKM)=KD*(PP/PG)**(-1.*SKM)
PSI(AAA,K)=ALPHG*K*AAA/AV
```

C

C The following parameters have been defined in program SAND and  
C are repeated here.

```
C AAV=(1.+EO)/(GAMMAWATER*(DELTA Y)**2)
C AAH=(1.+EO)/(GAMMAWATER*(DELTA H)**2)
C SKVM=CC/SKV if IAV=1, SKVM=2.3026*AVD/SKV if IAV=0
C SKHM=CC/SKH if IAV=1, SKHM=2.3026*AVD/SKH if IAV=0
C AVD= initial coeff. of compressibility
C KVD,KHD= initial coeff. in vert. and hori. dirns.
C ALPHG =gas factor.
```



IAV=0, constant AV=AVD. IAV=1, variable AV  
 IK=0, const. K-s. IK=1, variable K-s.  
 NNN=no. of points with vert. and hori. flow.  
 KOUNT=0 if the subroutine is called the second or following time  
 KOUNT=1 if the subroutine is used for the first time  
 ICOEF=1 if IK=0 and IAV=0 or IAV=1  
 ICOEF=2 if IK=1 and IAV=0  
 ICOEF=3 if IK=1 and IAV=1  
 ICOEF=4 if  $K*(1.+EO)/(GAMMAWATER*AV*DELTA\ Y**2)=CVIN$  and  
 $K*(1.+EO)/(GAMMAWATER*AV*DELTA\ H**2)=CHIN$  are  
 specified at ICV effective stresses PCV and PCH resp.  
 ISAT=0 full saturation, ISAT=1 partial saturation  
 PO= ave present overburden pressure  
 PCD= ave preconsol. pressure  
 DISU= UAVD-UAVE= ave dissipated pore pressure  
 CCC= 0.4343\*compression index  
 EOPUS=  $EO*PU*(1.-S*(1.-HC))$ , where PU=initial pore gas pressure,  
 S=initial degree of saturation, HC=Henry's const.  
 OMEGA(I)=(gas factor\*coeff. of consol)/delta H\*\*2  
 PHI(I)=(gas factor\*coeff. of consol.)/delta Y\*\*2  
 OMED(I)=difference between old and new omega(I)  
 PHID(I)=difference between old and new PHI(I)

IF (KOUNT.EQ.0) GO TO 20  
 ALPHG=1.  
 IF (IAV.EQ.1) PG=CCC/AVD

Determine OMEGA, PHI, OMED and PHID at NN points

Determine eff. stresses at the sum of the present overburden stress PO and the dissipated pore pressures DISU. Determine then the soil parameters as a function of PO+DISU

20 DO 5 I=1,NN  
 KK=ICOEF  
 DISU=UAVD(I)-UAVE(I)  
 PP=PO+DISU  
 AV=AVD  
 KV=KVO  
 KH=KHO  
 IF (KK.EQ.4) GOTO 6  
 IF (IAV.EQ.0) GO TO 6  
 IF (PP.GT.PG) GO TO 31  
 KK=1  
 GO TO 6  
 31 AV=CCC/PP  
 5 IF (ISAT.EQ.0) GO TO 60  
 AUX=AV  
 IF (PP.LT.PCD) AUX=AUX\*ROC  
 ALPHG=1./((1.+EOPUS/(AUX\*(PU+UAVE(I))\*\*2))  
 50 IF (IL.EQ.1) GO TO 7  
 IF (HF.EQ.0.) RETURN

PARAMETERS FOR HORIZONTAL CASE

if (KK.eq.1) go to 11  
 if (KK.eq.2) goto 12  
 if (KK.eq.3) goto 13  
 go to 14  
 12 KH=CONK(KHO,SKHM)

```

      GO TO 11
13     KH=VARK(KHO,SKHM)
11     A=PSI(AAH,KH)
      GO TO 30
C
C INTERPOLATE BETWEEN CHIN(I)
C
14     BB(1)=ALOG(PP)
      CALL LAGR(BB,AA,1,1,PCH,CHIN,ICV)
      A=ALPHG*AA(1)
30     IF (LI.EQ.3) OMED(NN+1-I)=OMEGA(NN+1-I)-A
      OMEGA(NN+1-I)=A
      GO TO 5
C
C PARAMETERS FOR VERTICAL CASE
C
7       IF (KK.EQ.1) GOTO 1
      IF (KK.EQ.2) GO TO 2
      IF (KK.EQ.3) GO TO 3
      GO TO 4
2       KV=CONK(KVO,SKVM)
      GO TO 1
3       KV=VARK(KVO,SKVM)
1       A=PSI(AAV,KV)
      GO TO 40
C
C INTERPOLATE BETWEEN CVIN(I)
C
C
4       BB(1)=ALOG(PP)
      CALL LAGR(BB,AA,1,1,PCV,CVIN,ICV)
      A=ALPHG*AA(1)
40      IF (LI.EQ.3) PHID(I)=PHI(I)-A
      PHI(I)=A
5       CONTINUE
C
      RETURN
      END
C BEGIN SUBROUTINE FUNCT
C
      SUBROUTINE FUNCT (THETA,ETA,K,SIGX,SIGY,TAU)
C
C This subroutine computes the values of the integrands for the
C argument theta
C
      COMMON/ POFUN/ Q(516),ETHST(516)
C
      TE=ETA*THETA
      ETE=EXP(TE)
      C=(ETHST(K)+1./ETHST(K))/2.
      S=(ETHST(K)-1./ETHST(K))/2.
      CTE=(ETE+1./ETE)/2.
      STE=(ETE-1./ETE)/2.
C
      D=Q(K)/(C*C+THETA*THETA)
      FA=C+THETA*S
      FB=THETA*TE
      FC=THETA*C
      FD=TE*CTE
      FE=TE*STE

```

# EVALUATE THE INTEGRANDS

```
SIGX=-D*(FA*(CTE+FE)-FC*(2.*STE+FD))
SIGY=-D*(FA*(CTE-FE)+FC*FD)
TAU=+D*(-FA*FD+FC*(CTE+FE))
IF (ETA.EQ.1.) RETURN
AUX=2.*G(K)*CTE/ETHST(K)
SIGX=SIGX+AUX
SIGY=SIGY+AUX
RETURN
END
```

## END OF SUBROUTINE FUNCT

```
SUBROUTINE PORE (XINP,YINP,M,NST,CX,IX,CY,IY,U,ABAR,BBAR)
```

This subroutine computes the stresses within a compressible soil layer by use of elastic theory for plane strain conditions. and a symmetric loading. Poissons ratio is 0.5 and the underlying stratum is perfectly rough and rigid. Pore pressures are computed from a knowledge of the stresses and the pore pressure coeff. A and B called herein ABAR and BBAR.

```
DIMENSION XINP(1),YINP(1),CX(1),CY(1),U(1),SX(220)
DIMENSION SY(220),TA(220),GX(516),GY(516),GT(516),SI(3)
DIMENSION SUM(3),R(3),T(3),DIF(3),AR(7),SUMS(3),ABSD(3)
```

```
COMMON/ SAPOD/ IOUPT,W,H,GLOAD,CLOAD,NARC,NRAD
COMMON/ POAPI/ ALPHA(30),L
COMMON/ POFUN/ GST(516),ETHST(516)
```

If no load is specified (No. of input points M.LE.1) set pore pressures equal to zero and return.

```
IF (M.GT.1) GO TO 101
DO 100 I=1,220
U(I)=0.
RETURN
```

Approximate actual load by NST strips of const. thickness DST.

```
101 CALL APROX (XINP,YINP,M,NST,DST)
WRITE (IOUPT,94) L
DO 10 I=1,L
WRITE (IOUPT,95) I,ALPHA(I)
10 ALPHA(I)=ALPHA(I)/H
```

Define constants used in the stress computation.

```
DELTA=0.0001
DEL=0.001
DELT=DELTA
PI=3.14159265358979
IMAX=512
AINT=1./512.
KEND=IMAX+1
PMAX=NST
PMAX=ABS(PMAX*PI/2.)
JEND=12
FAC=2.*GLOAD*DST/PI
```

```
      ZETA=W/H
      IXIY=IX*IY
      BRAN=2.
C
C Define constant for pore pressure determination.
C
      CONST=0.8660254*(ABAR-1./3.)+1./2.
C
C
C SET STRESSES EQUAL ZERO
C
      DO 21 I=1,IXIY
      SX(I)=0.
      SY(I)=0.
21    TA(I)=0.
C
      IER=0
C
C Initialize the numerical integration procedure
C Use Simpsons rule if XI.LT.BRAN
C Use Filons formula if XI.GE.BRAN
C Numerical integration is done between 0.0 and REAL(JEND)
C
      DO 5 ISTEP=1,JEND
C
      A=ISTEP-1
      B=ISTEP
      BA=1.
C
      IF (ISTEP.EQ.2) DELT=DEL
C
C Compute factors repeatedly used in subroutine FUNCT
C
      THETA=A-AINT
      DO 2 K=1,KEND
      THETA=THETA+AIN
      ETHST(K)=EXP(THETA)
      GST(K)=0.
C
      DO 2 I=1,L
      GI=ALPHA(I)
      AT=GI*THETA
      ABSAT=ABS(AT)
      IF (ABSAT.LT.0.001) GO TO 3
      GI=GI*SIN(ABSAT)/AT
3     IF (AT.LT.0.) GI=-GI
2     GST(K)=GST(K)+GI
C
C Integrate numerically between the limits A and B and store
C the results in one dimensional arrays SX,SY,TA
C
      DO 5 J=1,IY
      ETD=CY(J)
      ETA=1.-ETD
      DO 51 JGX=1,KEND
51    QX(JGX)=1.E15
C
C Evaluate the integrand at interval limits A and B
C
      CALL FUNCT (A,ETA,1,QX(1),QY(1),QT(1))
```

CALL FUNCT (B,ETA,KEND,GX(KEND),GY(KEND),GT(KEND))

DO 5 I=1,IX  
LL=(I-1)\*IY+J  
XI=CX(I)\*ZETA

INITIALIZE INTEGRATION

DO 41 K=1,3  
SI(K)=0.

XIA=XI\*A  
XIB=XI\*B  
SIXIA=SIN(XIA)  
SIXIB=SIN(XIB)  
COXIA=COS(XIA)  
COXIB=COS(XIB)  
IF (XI.LT.BRAN) GO TO 1  
DIF(1)=GX(KEND)\*SIXIB-GX(1)\*SIXIA  
DIF(2)=GY(KEND)\*SIXIB-GY(1)\*SIXIA  
DIF(3)=GT(1)\*COXIA-GT(KEND)\*COXIB  
R(1)=GX(1)\*COXIA+GX(KEND)\*COXIB  
R(2)=GY(1)\*COXIA+GY(KEND)\*COXIB  
R(3)=GT(1)\*SIXIA+GT(KEND)\*SIXIB

COMPUTE THE INTEGRAL BY INTERVAL HALVING

NHALF=1  
N=2  
AN=N  
HH=BA/AN  
XK=A-HH  
XINC=2.\*HH  
DO 44 K=1,3  
T(K)=0.

Compute the values of the integrands if not yet computed and store them in GX(K),GY(K),GT(K)

IDEL=IMAX/NHALF  
IT=-IMAX/N+1  
DO 8 K=1,NHALF  
XK=XK+XINC  
IT=IT+IDEL  
pq=1000000000000000.  
IF (GX(IT).EQ.pq) go to 55  
go to 56  
CALL FUNCT (XK,ETA,IT,GX(IT),GY(IT),GT(IT))  
XIX=XI\*XK

XIX=XI\*XK  
COXIX=COS(XIX)  
T(1)=T(1)+GX(IT)\*COXIX  
T(2)=T(2)+GY(IT)\*COXIX  
T(3)=T(3)+GT(IT)\*SIN(XIX)  
CONTINUE

IF (XI.GE.BRAN) GO TO 13

C SIMPSON RULE

C

HH=HH/3.

DO 46 K=1,3

46 SUM(K)=HH\*(R(K)+4.\*T(K))

GO TO 4

C

C Filons formula

C

C

13 XIH=XI\*HH

XXIH=XI\*XI

SIX=SIN(XIH)

COX=COS(XIH)

C=(SIX/XIH-COX)\*4.

D=XIH+SIX\*COX-2.\*SIX\*SIX/XIH

E=1.+COX\*COX-2.\*SIX\*COX/XIH

DO 47 K=1,3

47 SUM(K)=(D\*DIF(K)+E\*R(K)+C\*T(K))/XXIH

C

C CHECK FOR ACCRACY

C THE END RESULT WAS FOUND TO BE LITTLE AFFECTED EVEN WHEN THIS

C ACCURACY WAS NOT REACHED.

C

4 IF (NHALF.EQ.1) GO TO 16

SUMS(1)=SX(LL)+SUM(1)

SUMS(2)=SY(LL)+SUM(2)

SUMS(3)=TA(LL)+SUM(3)

C

C Accuracy as compared to the value of the integral between A and B

C

DO 48 K=1,3

ABSD(K)=ABS(SUM(K)-SI(K))

IF (ABSD(K).GT.ABS(DELT\*SUM(K))) GO TO 16

48 CONTINUE

C

IF (ISTEP.EQ.1) GO TO 17

C

C ACCURACY AS COMPARED TO THE MAXIMUM LOAD INTENSITY

C

```

DO 49 K=1,3
IF (ABSD(K).GT. (DELTA*PMAX)) GO TO 16
49 CONTINUE
GO TO 17

C
16 NHALF=N
N=2*NHALF
IF (N.LE. IMAX) GO TO 19
IF (IER.NE.0) GO TO 191
IER=1

C The Error Message at this point is supressed to reduce the
C volume of the out put.
C
C WRITE ERROR MESSAGE, IF N.GT. IMAX
C
191 continue
GO TO 17

C
C RENAME FOR NEXT CHECK OF ACCURACY
C
19 DO 50 K=1,3
SI(K)=SUM(K)
50 R(K)=R(K)+2.*T(K)
GO TO 6

C
17 SX(LL)=SUMS(1)
SY(LL)=SUMS(2)
TA(LL)=SUMS(3)

C
5 CONTINUE

C
C Stresses in X- and Y- Dirn. not including factor FAC
C
DO 15 J=1,IY
ETO=CY(J)
ETA=1.-ETO

C
DO 15 I=1,IX
XI=CX(I)*ZETA
LL=(I-1)*IY+J
IF (ETA.NE.1.) GO TO 30

C
C Stresses at the usrface (ETA.EQ.1) not including
C factor FAC. Use modified formula for stresses at the surface.
C
SX(LL)=SX(LL)-SY(LL)
SY(LL)=0.
DO 32 IS=1,L
ABSAL=ABS(ALPHA(IS))
IF ((XI/ABSAL)-1.) 33,34,32
33 SY(LL)=SY(LL)-2.*0.785398163397448*ALPHA(IS)/ABSAL
34 SY(LL)=SY(LL)-0.785398163397448*ALPHA(IS)/ABSAL
32 CONTINUE
SX(LL)=SX(LL)+SY(LL)
TA(LL)=0.
GO TO 31

C
C Stresses below the surface (ETA.LT.1) not including
C factor FAC
C

```

```

30      CALL INTEG (ETA,XI,B,AR)
        SX(LL)=SX(LL)-AR(1)+AR(2)-(3.-ETA)*AR(3)+AR(4)
        SY(LL)=SY(LL)-AR(1)-AR(2)-(1.+ETA)*AR(3)-AR(4)
        TA(LL)=TA(LL)+AR(5)+AR(6)-AR(7)

C
C Stresses in X- and Y- dirn and principal stresses
C Tension is positive
C
31      SSUM=(SX(LL)+SY(LL))/2.
        SDIF=(SX(LL)-SY(LL))/2.
        ROOT=SQRT(SDIF*SDIF+TA(LL)*TA(LL))
        SX(LL)=FAC*SX(LL)
        SY(LL)=FAC*SY(LL)
        TA(LL)=FAC*TA(LL)
        S1=FAC*(SSUM-ROOT)
        S2=FAC*(SSUM+ROOT)

C
C Compute pore pressures for plane strain Conditions with
C poissons ratio of 0.5 using skemptions pore pressure parameters
C A and B, herein called ABAR and BBAR.
C CONST was earlier defined as CONST=0.5*(ABAR-1/3)+1/2.
C
        U(LL)=-BBAR*(S2+(S1-S2)*CONST)
15      CONTINUE
        WRITE (IOUTP,93)

C
C FORMAT STATEMENTS
C
C
93      FORMAT (////////)
94      FORMAT (1H ,10X, 'THE ACTUAL LOAD IS APPROXIMATED BY ',I3, /
1       11x, ' LOADS OF EQ INTNSTY WHICH EXTEND FROM X=0 TO ALPHA(I)',
2       1H ,10X, 'IF ALPHA(I) IS NEGATIVE, THIS LOAD IS SUBTRACTED',//)

C
95      FORMAT (1H ,15X, 'ALPHA(',I2, ' ) = ',F10.3, ' FEET')

C
C
C
        RETURN
        END

C
C END OF SUBROUTINE PORE
C BEGIN SUBROUTINE DISP
        SUBROUTINE DISP (U,LI,OMEGA,PHI,T,UAVE,LIFT,MYE,IEND,XT,SV)

C
C
C This subroutine computes the pore pressures at time T by
C treating the consolidation equation as an eigenvalue
C problem.
C U      Pore pressures to be output. For LI=5,6 this vector
C        contains the additional pore pressures for the new load
C        when this subroutine is called.
C LI     Load identifier.
C LI=1   Determination of vectors A and B for the load addition.
C LI=2   Determination of pore pressures due to the stepwise
C        const. loads.
C LI=3   Determination of vectors A and B for times between
C        load application if the soil parameters are variable.
C LI=5   First LIFT , first use of DISP.
C ISP=1  Compute and print the pore pressures at all points of

```



```

C      the solution domain.
C ISP=0 Compute only the average pore pressures at different
C      depths at all IEND points.
C IVAR  identifier for soil parameters
C IVAR=0 Constant soil parameters
C IVAR=1 Variable soil parameters
C PHI   Vector depending on the soil parameters for vert. flow.
C OMEGA vector depending on the soil parameters for H-flow.
C T     Time
C LIFT  no. of vectors A and B
C M     Program numbering system, No. of points in Vert. Dirn.
C N     Program numbering system, No. of points in H-dirn.
C Storage reservations are made for 40 horizontal points and
C 6 step loads.
C
C      DIMENSION U(1),PHI(1),OMEGA(1),UAVE(1),XT(1),SV(1)
C      DIMENSION EIGV(10),EIGX(40),AUX(160),XV(100),XVI(100)
C      DIMENSION XH(1600),XHI(1600),FH(500),F(200),A(1200),B(1200)
C      DIMENSION VJ(11),RJ(40),RJJ(20),G(280),UBAV(240),UBB(20)
C      DIMENSION W1(300)
C
C      EQUIVALENCE (G(1),A(501))
C
C      COMMON/ SAPOD/ IOUTP,W,H,GLOAD,CLOAD,NARC,NRAD
C      COMMON/ SADI1/ LAYER,IBCV,MHE,M,N,IDC,NDR,ISUM,XET(41)
C      COMMON/ SADI2/ FIMPV,RC,RK,C,RO,RE,TA,ISP,IVAR
C
C      ief=64
C
C      LIM=LI
C      IF (LI.LT.5) GO TO 2
C      IF (LAYER.LT.3) LAYER=2
C
C Call MODAL for determination of eigen values, modal matrix and
C inverse of the modal matrix for the case of vertical and
C Hori. flow
C
C      CALL MODAL (LAYER,IBCV,M,FIMPV,RC,RK,O.,H,EIGV,XV,XVI,AUX)
C PAGE 60
C      IF (IDC.EQ.1) GO TO 1
C      CALL MODAL (1,4,N,FIMPV,RC,RK,RO,RE,EIGX,XH,XHI,AUX)
1      LIM=1
C
C Determine the diagonal matrices F and FH
C
2      CALL EFGEN (PHI,T,EIGV,IVAR,IEND,M,F,LI)
C      IF (IDC.EQ.1) GO TO 3
C      CALL EFGEN (OMEGA,T,EIGX,IVAR,1,N,FH,LI)
C
C BRANCH DEPENDING ON THE VALUE OF LIM
C
3      GO TO (4,5,6),LIM
C
C LIM=1
C DETERMINE VECTORS A AND B FOR THE LIFT-TH LOAD ADDITION
C *****
C Determination of VECTOR B for the LIFT-th load addition
C
4      IB=(LIFT-1)*M*IEND

```

```

      IE=0
      DO 10 K=1, IEND
      DO 11 I=1, M
      IA=(K-1)*MYE+1
      II=I-M
      IB=IB+1
      IE=IE+1
      B(IB)=0.
      DO 12 J=1, M
      II=II+M
      IA=IA+1
12      B(IB)=B(IB)+XVI(II)*U(IA)
          do 340 iief=1, ief
340          B(IB)=B(IB)/F(IE)
11      continue
10      CONTINUE
C
      IF (IDC.EQ.1) GO TO 13
C DETERMINE VECTOR A--HORIZONTAL CASE
C
      II=0
      LIN=(LIFT-1)*N+1
      LIN2=LIFT*N
      do 121 I=1, IEND
      UBB(I)=0.
      do 120 J=1, MYE
      II=II+1
      UBB(I)=UBB(I)+U(II)*SV(J)
120      continue
121      continue
      call LINT (XET,UBAV,N,LIN2,XT,UBB,IEND)
C To avoid numerical instability put UBAV(I)=0.1 if it is zero.
C
      do 1210 I=LIN,LIN2
          if (ABS(UBAV(I)).LT.0.1) UBAV(I)=0.1
1210      continue
      IS=(LIFT-1)*N
      DO 14 I=1, N
      IE=0
      II=I-N
      IS=IS+1
      A(IS)=0.
      IA=LIN2+1
      DO 15 J=1, N
      II=II+N
      IA=IA-1
      IE=IE+1
15      A(IS)=A(IS)+XHI(II)*UBAV(IA)
          do 341 iief=1, ief
341          A(IS)=A(IS)/FH(I)
14      CONTINUE
C
13      IF (ISP.EQ.0) RETURN
C LIM=2
C DETERMINE THE PORE PRESSURES AT TIME T AT XT(J), J=1, IEND
C *****
C
5      NM=M
      III=MYE
      DO 50 I=1, ISUM

```

```

50      U(I)=0.
C
      DO 51 J=1, IEND
C
      RJAVE=1.
      ID=(J-1)*M+1
      IE=(J-1)*N+1
C CONSIDER INFLUENCE OF LIFT LOADS
C
      DO 53 K=1, LIFT
      IB=ID+M*IEND*(K-1)
      CALL MAMULP (XV, F, B, VJ, M, IB, ID)
C
C BRANCH IF VERT FLOW ONLY
C
      IF (IDC.EQ.1) GO TO 54
      IB=1+N*(K-1)
C
      goto 54
      CALL MAMULP (XH, FH, A, RJ, N, IB, 1)
      do 75 IR=1, N
      RJ(IR)=RJ(IR)/UBAV(K*N+1-IR)
75      continue
C
      DO 650 IR=1, N/2
      HOLD=RJ(IR)
      RJ(IR)=RJ(N-IR+1)
      RJ(N-IR+1)=HOLD
650      continue
C
Determine the average pore pressures at M+1 points in
vertical direction at XT(J). Include the free drainage at
the upper boundary. The result after LIFT cycles of loop 53
is returned to the calling program. The drainage at the
lower boundary is considered outside loop 53.
      CALL LAGR (XT, RJJ, IEND, 1, XET, RJ, N)
      call LINT (XT, RJJ, IEND, IEND, XET, RJ, N)
C
54      II=(J-1)*MYE+1
      U(II)=0.
      DO 57 I=1, M
      II=II+1
      IF (IDC.EQ.1) GO TO 55
      RJAVE=RJJ(J)
      if (RJAVE.LT.0.) RJAVE=0.0
      GO TO 57
55      RJAVE=1.
57      U(II)=U(II)+VJ(I)*RJAVE
53      CONTINUE
C
      IF (IBCV.EQ.3) GO TO 58
      II=J*MYE
      U(II)=FIMPV*U(II-1)
C
58      IF (ISP.EQ.0) GO TO 59
      IF (IDC.EQ.1) GO TO 60
C
Output the pore pressures at XT(J) for the case of Vert+ Hor flow
      WRITE (IDOUTP, 94) T, XT(J)

```

```

      GO TO 62
C
C Output the pore pressures at XT(J) for the case of Vert flow only
C
  60      WRITE (IOUTP,91) T,XT(J)
  62      II=(J-1)*MYE
          DO 61 I=1,MYE
              II=II+1
  61      WRITE (IOUTP,92) U(II)
          WRITE (IOUTP,93)
          GO TO 59
C
C Compute the ave pore pressures at XT(J)
C
  59      II=(J-1)*MYE
          UAVE(J)=0.
          DO 63 I=1,MYE
              II=II+1
  63      UAVE(J)=UAVE(J)+U(II)*SV(I)
C
  51      CONTINUE
          RETURN
C
C
C Determine vectors A and B for the case of variable soil para-
C meters and times between load applications LIM=3
C *****
C
C Determine vector B
C
  6      II=IEND*M
          IB=0
          DO 20 K=1,LIFT
              DO 20 I=1,II
                  IB=IB+1
                      do 20 iief=1,iief
  20      B(IB)=B(IB)*F(I)
C
          IF (IDC.EQ.1) RETURN
C
C DETERMINE VECTOR A
C
          II=N
          IA=0
          DO 22 K=1,LIFT
              DO 22 I=1,II
                  IA=IA+1
                      do 22 iief=1,iief
  22      A(IA)=A(IA)*FH(I)
          RETURN
C
C FORMAT STATEMENTS
C
  91      FORMAT (/////,1H ,10X,'T= ',F6.0,' DAYS,X/W= ',F8.3, /
  1      ' PORE PRESSURES IN PSF-VERTICAL FLOW ONLY',/)
  92      FORMAT (1H ,10X,11F10.3)
  93      FORMAT (////)
  94      FORMAT (/////,1H ,10X,'T= ',F6.0,' DAYS X/W = ',F8.3, /
  1      ' PORE PRESSURES IN PSF DUE TO VERT + HORI FLOW',/)
C

```

END

C  
C END OF SUBROUTINE DISP  
C  
C SUBROUTINE SETL BEGINS  
C

SUBROUTINE SETL (U,SETTL,IEND,KKK,MYE,F,FUP,FLO,KIAV)

C This usbroutine computes consol. (F=1) or total (F.GT.1)  
C settlements using constant (KIAV=1+IAV=1) or variable KIAV=2  
C soil parameters.

C U Vector of dissipated pore pressures with IEND\*MYE  
C elements.  
C SVM Modified mathematical molecule for Simpsons or  
C trapezoidal formula (considers case of stratified  
C soil if LAYER.GT.2)  
C SETTLL Vector of computed settlements with IEND elements  
C IEND No. of settlements  
C KKK No. of distinct pore pressures in the upper layer  
C MYE No. of distinct pore pressures in both layers  
C F Consol. settlements are computed if F=1.0  
C Total settlements are Computed if F=1./B where  
C B= Skempton pore pressure coeff.  
C FUP Parameter for the upper layer which incorporates  
C the soil coeff.  
C FLO Corresponding parameter for the lower layer.

DIMENSION U(1),SETTL(1),SVM(12),P(11),PC(11),PLOG(11)

COMMON/ SACSE/ ROC,ROCL,SVM,P,PC,PLOG,PO,PCO,IAV,IK,ISAT,AAV,AAF

C  
C  
C ISE=ISE+1  
901 format ('NO. of times entered SETL =',I5)  
write (IOUTP,901) ISE  
R=ROC  
A=FUP  
II=-MYE  
JST=1  
JND=KKK  
JSS=0

C  
1 DO 1 I=1,IEND  
SETTL(I)=0.

6 DO 2 I=1,IEND  
II=II+MYE  
IU=II  
S=0.  
JS=JSS

C  
DO 3 J=JST,JND  
IU=IU+1  
JS=JS+1  
GO TO (4,5),KIAV

C Constant soil parameters IAV=0 KIAV=1

4 S=S+F\*SVM(JS)\*U(IU)  
GO TO 3

```

C
C Variable soil parameters IAV=1 KIAV=2
C
5      PP=P(J)+F*U(IU)
C      if the current effective stress at some point becomes
C      negative then it is put as P(J) at that point.
C      i.e no swelling is considered.
C
      if (PP.LT.P(J)) PP=P(J)
      IF(PP.GT.PC(J)) GO TO 7
      S=S+R*SVM(JS)*ALOG(PP/P(J))
C
C
      GO TO 3
7      S=S+SVM(JS)*(ALOG(PP/PC(J))+R*PLOG(J))
3      CONTINUE
      SETTLE(I)=SETTLE(I)+A*S
2      CONTINUE
C
C Consol. of the lower layer
C
      IF (JND.EQ.MYE) RETURN
      A=FLO
      R=ROCL
      II=KKK-MYE-1
      JST=KKK
      JND=MYE
      JSS=KKK
      GO TO 6
      END
C
C END OF SETTLE
C BEGIN SUBROUTINE MAMULP
C
      SUBROUTINE MAMULP (A,D,B,C,N,IS,II)
C
C This subroutine performs the matrix multiplication
C (General matrix A)*(Diagonal matrix D)*(Vector B) = (Vector C)
C All matrices are stored one dimensionally with A having N*N
C elements and D,B,C each having N elements. The first element
C of B and D are B(IS) and D(II)
C
C The formula for the I-th element of C is
C C(I)=SUM(K=1,N) of A(I+(K-1)*N)*B(IS-1+K)*D(II+K-1)
C
      DIMENSION A(1),B(1),C(1),D(1)
C
      ief=64
      do 1 I=1,N
      IA=N*N+I
      IB=IS+N
      ID=II+N
      C(I)=0.
      DO 1 K=1,N
      IB=IB-1
      ID=ID-1
      IA=IA-N
      cc=A(IA)*B(IB)
          do 20 iief=1,ief
              cc=D(ID)*cc

```

```

      C(I)=C(I)+cc
1      CONTINUE
      RETURN
      END

C
C END OF SUBROUTINE MAMULP
C SUBROUTINES BEGIN HERE.
C
      SUBROUTINE OVERFLO (J)
C
C
      J=1
      RETURN
      END
      SUBROUTINE HDIST (UB, XT, IEND, ICV, CHIN, DXSQ, AAH, MHE, W, XET, IPOR, HF
*, MYE, POR)
C Begin subroutine computes the horizontal distance from the
C center line to the point
C where the pore pressure is 0.1% of the maximum pore
C pressure under the embankment. This is taken to be the Hori. drainage
C distance. This subroutine will be active only once.
      dimension UB(1), XT(1), CHIN(1), XET(1)
      if (HF.eq.0.) goto 100
      if (IPOR.eq.1) goto 100
C Find maximum pore pressure
      do 50 i=1, IEND
      if (umax.lt.UB((i-1)*MYE+1)) umax=UB((i-1)*MYE+1)
50      continue
      umin=umax*0.001
      i=1
60      if (UB((i-1)*MYE+1).lt.umin) goto 65
      i=i+1
      if (i.lt.(IEND+1)) goto 60
      POR=1.+(1.-XT(IEND-1)/XT(IEND))*(UB((IEND-1)*MYE+1)-umin)/(UB((
*IEND-2)*MYE+1)-UB((IEND-1)*MYE+1))
      goto 70
65      POR=(XT(i-1)+(XT(i)-XT(i-1))*(UB((i-2)*MYE+1)-umin)/(UB((
ii-2)*MYE+1)-UB((i-1)*MYE+1)))/XT(IEND)
70      IPOR=1
C
C Redefine horizontal grid points and the related parameters
C using new horizontal drainage distance.
C
      do 529 I=1, ICV
      CHIN(I)=CHIN(I)*DXSQ
529      continue
      AAH=AAH*DXSQ
      AI=MHE-1.
      DHX=POR*XT(IEND)*W/AI
      do 25 I=1, MHE-1
      XET(I)=POR*(I-1)*XT(IEND)/AI
25      continue
      DXSQ=DHX*DHX
      AAH=AAH/DXSQ
      do 530 i=1, ICV
      CHIN(i)=CHIN(i)/DXSQ
530      continue
      write (IATP, 778)POR
778      format ('NEW POR=', f10.5)
100      return

```

```
      end
C End of subroutine HDIST
      SUBROUTINE APROX (X,Y,MN,N,D)
C
C This subroutine approximates the actual load by N strips of
C constant thickness D
C
      DIMENSION X(1),Y(1),XA(25),YA(25)
      COMMON/ POAPI/ ALPHA(30),L
C
C
C DETERMINE MAX VALUE OF Y(1)
C
      M=MN
      YMAX=Y(1)
      DO 1 I=2,M
      IF (Y(I).GT.YMAX) YMAX=Y(I)
1      CONTINUE
C
C Initiate first step starting with X(M) and Y(M)
C
      AN=N
      D=YMAX/AN
      L=1
      H=Y(M)
      XX=X(M)
      XA(1)=0.
C
C Compute the portion between two horizontal lines with distance D
C
2      YA(1)=H
      K=2
      XA(K)=XX
      YA(K)=H
      H=H+D
C
C If statement because of possible truncation error
C
      IF (ABS(H-YMAX).LT.0.001) H=YMAX
3      MM=M-1
      IF (MM.EQ.0) GO TO 4
      XX=(X(M)-X(MM))*(H-Y(MM))
C
      IF (ABS(Y(M)-Y(MM)).LT.0.01) J=1
      IF (ABS(Y(M)-Y(MM)).LT.0.01) CALL OVERFLO (J)
      IF (ABS(Y(M)-Y(MM)).LT.0.01) GO TO 61
      XX=XX/(Y(M)-Y(MM))
C
C If the denominator approaches zero, J is set equal to 1
C
61      IF (J.NE.1) GO TO 5
6      K=K+1
      J=0
      XA(K)=X(MM)
      YA(K)=Y(MM)
      M=MM
      GO TO 3
5      XX=XX+X(MM)
      IF (ABS(XX-X(MM)).LT.0.001) GO TO 8
      IF (XX.LT.X(MM)) GO TO 6
      MM=M
```



```

      GO TO 9
      M=MM
8
C
9      K=K+1
      XA(K)=XX
      YA(K)=H
4      XA(K+1)=0.
      YA(K+1)=H
      A=0.
      DO 10 I=1,K
      J=I+1
      A=A+XA(I)*YA(J)-YA(I)*XA(J)
10     CONTINUE
C
C Determine width of constant load equivalent to portion between
C two horizontal lines with distance D.
C ALPHA is negative if this portion is to be subtracted.
      ALPHA(L)=A/(2.*ABS(D))
      IF (L.EQ.N) GO TO 11
13     IF (ALPHA(L).EQ.0.) L=L-1
      IF (MM.EQ.0) GO TO 12
      L=L+1
      GO TO 2
11     IF (YMAX.LE.Y(1)) GO TO 12
      D=-1.*D
      GO TO 13
12     D=ABS(D)
      RETURN
      END
C
C
C
C
C
C SUBROUTINE DETFS
      SUBROUTINE DETFS (XC,YC,R,XINP,YINP,MINP,MX,MYE,SU,FS)
C
C This subroutine determines the factor of safety against failure
C along a circular arc by taking the ratio of the resisting and
C driving moments about the center of the arc. Shear strengths
C along that part of the arc, which passes through the subsoil
C are obtained by interpolating between the elements of vector SU.
C This is an analysis in terms of TOTAL STRESSES.
C
      DIMENSION XINP(1),YINP(1),SU(1),XS(22),YS(22),X(2)
      DIMENSION WWW(2),XAUX(10),YAUX(10),SINUS(2),COSIN(2)
C
      REAL MD,MR
C
      COMMON/ INDET/ RHO(19),TAU(19),PSI(19)
      COMMON/ SAPOD/ IDOUTP,W,H,GLOAD,CLOAD,NARC,NRAD
      COMMON/ SADET/ XSTAB(51),YSTAB(11),DX,DY,YWM,TGPHI
C
C STATEMENT FUNCTIONS
C
      FUNA(A,B) =(XC+A*AA)/B
      FUNB(B)    =AB*AB+(RX-AA*AA)/B
      FUNC(A,B,C)=A+B*(C-A)
C
C The parameters have the following significance

```

```

C XC,YC coord of the center of the arc.
C R      radius of the arc
C XINP,YINP Coord of the points describing the X-section of
C         the embankment.
C MINP   No. of points XINP/YINP
C MX     No. of equally spaced points in X-dirn.
C MYE    No. of equally spaced points in Y-dirn.
C SU     Vector of shear strengths with MX*MYE elements
C FS     Factor of safety
C RHO(I) Slope of the line connecting XINP(I)/YINP(I) and
C         XINP(I+1)/YINP(I+1)
C PSI(I) YINP value of the above line for XINP=0.
C TAU(I) TAU(I)=1.+RHO(I)*RHO(I)
C GLOAD  unit weight of the embankment soil
C CLOAD  Shear strength of the embankment soil
C XSTAB  MX equally spaced points in X-dirn.
C YSTAB  MYE equally space points in Y-dirn.
C DX,DY  Intervals in X- and Y-dirn.
C NARC   One-half no. of subarcs within subsoil
C
C
C         ANARC=2*NARC
C         MXM=MX-2
C         RR=R*R
C         XX=XC*XC
C         RX=RR-XX
C         YY=YC*YC
C         LAST=0
C
C POINTS OF INTERSECTION BETWEEN ARC AND SURFACE
C
C         AA=SQRT(RR-YY)
C
C
C         XS(1)=XC-AA
C         XG=XC+AA
C         IF (XG.GE.XINP(MINP)) LAST=1
C
C POINT OF INTERSECTION BETWEEN ARC AND EMBANKMENT SURFACE
C
C         I=0
C         J=2
C         1 I=I+1
C           AA=YC-PSI(I)
C           AB=FUNA(RHO(I),TAU(I))
C           AA=FUNB(TAU(I))
C           IF (AA.LT.0.) GO TO 1
C           AA=SQRT(AA)
C           XT=AB-AA
C           IF (XT.GE.XINP(I+1)) GO TO 1
C           XS(2)=XT
C           YS(2)=XT*RHO(I)+PSI(I)
C
C Resisting moment MR due to the arc between XS(1)/YS(1)=0. and
C XS(2)/YS(2) within the embankment. Driving moment MD due to
C the segment between XS(1)/0. and XS(2)/YS(2).
C
C         BETA1=0.5*ASIN(YC/R)
C         BETA2=0.5*ASIN((YC-YS(2))/R)
C         MR=2.*RR*CLOAD*(BETA1-BETA2)

```

```

A=XS(1)-XS(2)
A=SQRT(A*A+YS(2)*YS(2))
MD=(A*A*A*COS(BETA1+BETA2))/2.
IF (LAST.EQ.0) GO TO 2

```

C  
C THE POINTS XS/YS ARE EQUAL TO THE POINT S XINP/YINP  
C

```

I=I+1
DO 3 K=I,MINP
J=J+1
XS(J)=XINP(K)
3  YS(J)=YINP(K)
31 LAST=J
GO TO 7

```

C  
C Determine the second point of intersection between the arc and the  
C embankment surface. Store all points in XS/YS which lie between  
C this point and the point XS(2)/YS(2).

```

2  XT=AB+AA
   IF (XT.LE.XINP(I+1)) GO TO 4
5  I=I+1
   J=J+1
   XS(J)=XINP(I)
   YS(J)=YINP(I)
   IF (I.EQ.MINP) GO TO 31
   IF (XINP(I+1).GT.XG) GO TO 6
   IF (YINP(I+1).LT.YC) GO TO 5
6  AA=YC-PSI(I)
   AB=FUNA(RHO(I),TAU(I))
   AA=FUNB(TAU(I))
   AA=SQRT(AA)

   GO TO 2
4  J=J+1
   XS(J)=XT
   YS(J)=XT*RHO(I)+PSI(I)

```

C  
C Resisting and driving moments due to the arc and the segment  
C between the points XS(J)/YS(J) and XG/O.

```

BETA2=0.5*ASIN((YC-YS(J))/R)
LAST=J+1
XS(LAST)=XG
YS(LAST)=0.
MR=MR+2.*RR*CLOAD*(BETA1-BETA2)
A=XG-XS(J)
A=SQRT(A*A+YS(J)*YS(J))
MD=MD-(A*A*A*COS(BETA1+BETA2))/2.

```

DRIVING MOMENTS DUE TO TRIANGLES WITH ONE APEX AT XS(1)/O.

```

7  XX=3.*XC-XS(1)
   DO 8 I=3, LAST
   J=I-1
   A=XS(1)*(YS(I)-YS(J))-XS(J)*YS(I)+XS(I)*YS(J)
   MD=MD+(XX-XS(J)-XS(I))*A
8  CONTINUE

```

RESISTING MOMENT DUE TO THE PART OF THE ARC WHICH PASSES THROUGH

C TH SUBSOIL

C

IF (H.EQ.0.) GO TO 100

IF (MYE.EQ.1) GO TO 20

C

C Resisting moment along subarcs in the subsoil. The shear  
C strengths along the 2\*NARC subarcs are assumed const and  
C obtained by linear interpolation between the appropriate  
C values of SU.

C

DARC=(3.1415927-4.\*BETA1)/ANARC

RARC=RR\*DARC

BETA=2.\*BETA1-DARC/2.

DO 9 L=1,NARC

BETA=BETA+DARC

A=R\*COS(BETA)

X(1)=XC-A

X(2)=XC+A

A=R\*SIN(BETA)-YC

AJ=A/DY+1.

J=AJ

FY=(A-YSTAB(J))/DY

C

DO 10 K=1,2

AI1=X(K)/DX

I=AI1

IF (I.LE.MXM) GO TO 11

C

C Midpoint of the subarc lies outside the domain for which  
C SU-s are specified. Interpolation is done in Y-dirn only  
C between the values SU(MX\*(MYE-1)+1) through SU (MX\*MYE).

C

IJ=J+(MX-1)\*MYE

JJ=IJ+1

AA=SU(IJ)

AB=SU(JJ)

GO TO 12

C

C Interpolation for the midpoint of the subarc. Two linear  
C interpolation are performed in X-dirn. One linear interp-  
C olation is performed in Y-dirn between the values obtained.

C

11 IJ=J+I\*MYE

JJ=IJ+MYE

I=I+1

FX=(X(K)-XSTAB(I))/DX

AA=FUNC(SU(IJ),FX,SU(JJ))

IJ=IJ+1

JJ=JJ+1

AB=FUNC(SU(IJ),FX,SU(JJ))

12 MR=MR+RARC\*FUNC(AA,FY,AB)

10 CONTINUE

DM=MD\*GLOAD/6.

9 CONTINUE

GO TO 100

20 RARC=RR\*(3.1415927-4.\*BETA1)

MR=MR+SU(1)\*RARC

C

C Factor of safety.

C

```

100    MD=MD*GLOAD/6.
C
C IF THERE IS AN OVERFLOW CONDITION, J IS SET .EQ. 1 AND
C FS IS SET .EQ. 1.0E50
C
      JJJ=0
      IF (MD.LT.0.000000000000000001) CALL OVERFLO (JJJ)
      IF (MD.LT.0.000000000000000001) GO TO 111
      FS=MR/MD
111    IF (JJJ.NE.1) GO TO 40
      FS=100.
      JJJ=0
      RETURN
C
C Determination of the resisting moment due to friction.
C
40     IF (YWM.EQ.0.) RETURN
      IF (FS.LT.0.0001) FS=1.
      FAC=TGPHI/FS
      RMR=MR
      KOUNT=1
      XAUX(1)=XS(1)
      YAUX(1)=0.
      AB=YC-YWM
      AB=SQRT(RR-AB*AB)
      XAUX(2)=XC-AB
      YAUX(2)=YWM
      IF (XAUX(2).GE.XS(2)) GO TO 41
      XAUX(2)=XS(2)
      YAUX(2)=YS(2)
41     BETA2=0.5*ASIN((YC-YAUX(2))/R)
      XAUX(3)=XAUX(2)
      K=3
      I=1
43     I=I+1
42     IF (XAUX(K)-XINP(I)) 44,45,43
45     YAUX(K)=YINP(I)
      GO TO 46
44     YAUX(K)=RHO(I-1)*XAUX(K)+PSI(I-1)
46     K=K+1
      IF (XAUX(1).LE.XINP(I)) GO TO 47
      XAUX(K)=XINP(I)
      YAUX(K)=YINP(I)
      I=I+1
      GO TO 46
47     XAUX(K)=XAUX(1)
      YAUX(K)=RHO(I-1)*XAUX(1)+PSI(I-1)
      XAUX(K+1)=XAUX(1)
      YAUX(K+1)=YAUX(1)
      WW=0.
      DO 48 J=1,K
      L=J+1
      WW=WW-XAUX(J)*YAUX(L)+YAUX(J)*XAUX(L)
48     CONTINUE
      WWW(KOUNT)=WW*GLOAD/2.
      AA=XAUX(1)-XAUX(2)
      BB=YAUX(2)-YAUX(1)
      CC=SQRT(AA*AA+BB*BB)
      SINUS(KOUNT)=BB/CC
      COSIN(KOUNT)=AA/CC

```

```

RMR=RMR-2.*RR*CLOAD*(BETA1-BETA2)
IF (KOUNT.EQ.2) GO TO 49
IF (XS(LAST).EQ.XINP(MINP)) GO TO 49
KOUNT=2
XAUX(1)=XC+AB
YAUX(1)=YWM
IF (XAUX(1).LE.XS(LAST-1)) GO TO 50
XAUX(1)=XS(LAST-1)
YAUX(1)=YS(LAST-1)
50  BETA2=0.5*ASIN((YC-YAUX(1))/R)
    XAUX(2)=XS(LAST)
    YAUX(2)=0.
    XAUX(3)=XAUX(2)
    K=3
    GO TO 42
C ITERATION FOR THE CORRECT FACTOR SAFETY
C
49  MR=RMR
    DO 51 I=1,KOUNT
    MR=MR+FAC*WWW(KOUNT)*R/(COSIN(KOUNT)+FAC*SINUS(KOUNT))
51  CONTINUE
    FSOLD=FS
    FS=MR/MD
    IF (ABS(FS-FSOLD).LT.0.001) RETURN
    FAC=TGPHI/FS
    GO TO 49
    END
C END OF SUBROUTINE DETFS
C
C BEGIN SUBROUTINE GAIN
C
    SUBROUTINE GAIN (UA,R,SU,MYE,MXT,MXE,MX,NIM,CO,CP,III)
C
C This subroutine determines the shear strengths at MX*MYE points
C XE/YE from a knowledge of the initial shear strengths CO and
C the C/PBar=CP-ratios
C
C UA Dissipated pore pressures at XT/YE
C R Auxiliary matrix for the computation of the dissipated pore
C pressures at XT/YE from those at XT/YE
C SU Shear strengths at XE/YE. SU(XE/YE) is equal to the initial
C shear strength CO(YE) plus the product of the dissipated
C pore pressure at XE/YE and the C/PBar-ratio CP(YE)
C MYE No. of points YE in vertical direction.
C NIM No. of intervals in horizontal Dirn.
C MXT NIM numbers of points XT in each interval.
C MXE NIM no. of points in XE in each interval
C MX Total no. of points XE
C CP Vector of MYE C/PBAR-ratios
C CO Vector of MYE initial shear strengths
C III Index for the identification of the following cases--
C If III=1, all elements of UA are assumed to be zero.
C If III=0, some or all elements of UA are not equal to zero
C
    DIMENSION UA(1),R(1),SU(1),MXT(1),MXE(1),CO(1),CP(1)
C
    K=0
    IF (III.EQ.0) GO TO 1
C
C ALL ELEMENTS OF UA ARE EQUAL TO ZERO

```

C

```
DO 2 I=1,MX
DO 2 J=1,MYE
K=K+1
SU(K)=CO(J)
CONTINUE
RETURN
```

2

C

C The shear strength consists of the initial strength plus some  
C gain due to dissipated pore pressures

C

1

```
IUBE=0
IUND=0
IRND=0
DO 3 JJ=1,NIM
IUBS=IUBE+1
IUBE=IUBE+MYE*MXT(JJ)
IUST=IUND+1
IUND=IUND+MYE*MXE(JJ)
IRST=IRND+1
IRND=IRND+MXT(JJ)*MXE(JJ)
CALL MPRD (UA,R,SU,MYE,MXT(JJ),MXE(JJ),IUBS,IRST,IUST)
CONTINUE
```

3

C

```
DO 4 I=1,MX
DO 4 J=1,MYE
K=K+1
SU(K)=CO(J)+SU(K)*CP(J)
```

4

```
CONTINUE
RETURN
END
```

END OF SUBROUTINE GAIN

BEGIN SUBROUTINE GENER

SUBROUTINE GENER (P,F,X,N)

C This subroutine generates the N+1 Coeff. of the characteristic  
C equation of the tridiagonal matrix P  
C The coeff. are stored in vector A. P must be supplied as a one-  
C dimensional array with 2\*N elements. An auxiliary vector F with  
C ((N+1)\*(N+4)/2-2) elements is used for computation. Vector X  
C contains the N roots of the characteristic equation.

```

C      DIMENSION P(1),A(25),F(2),X(1)

C      IC=0
C      F(1)=0.
C      F(2)=1.0
C      IF=2
C      NF=N

C
C COMPUTE F(3) THRU F(N+2)
C
      DO 1 I=1,NF
        IF =IF+1
        IP=2*I
        F(IF)=P(IP-1)*F(IF-2)+P(IP)*F(IF-1)
1      CONTINUE

C
4      IC=IC+1
      A(IC)=F(IF)
      IF(IC.EQ.N) GO TO 3
      NF=NF-1

C
C COMPUTE F(N+3) THRU F((N+1)*(N+4)/2-2)
C
      F(IF+1)=0.
      IF=IF+2
      II=IF-NF-3
      IP=2*IC
      F(IF)=1.
      DO 2 I=1,NF
        IF=IF+1
        II=II+1
        IP=IP+2
        F(IF)=P(IP-1)*F(IF-2)+P(IP)*F(IF-1)+F(II)
2      CONTINUE
      GO TO 4

C
3      A(IC+1)=1.

C
C CALL RROOT FOR DETERMINATION OF THE REAL ROOTS
C
      CALL RROOT (A,X,N)

C
      RETURN
      END

C
C END OF SUBROUTINE GENER
C BEGIN SUBROUTINE GENS
C
      SUBROUTINE GENS (S,M)

```

C This subroutine generates the mathematical molecule for the  
C extended simpsons (1/3) rule or the extended trapezoidal  
C rule. Each element is divided by the total length of the



C integration interval, thus making it only dependent on the  
C number (M-1) of subintervals.

C

DIMENSION S(1)

C

IF (M.LE.1) RETURN

MM=M-1

FAC=MM

IF (M.EQ.(M/2)\*2) GO TO 3

C

C SIMPSON-S RULE IF M IS ODD

C

FAC=1./(3.\*FAC)

I=1

S(1)=FAC

I=I+1

S(I)=4.\*FAC

I=I+1

S(I)=FAC

IF (I.EQ.M) RETURN

S(I)=2.\*FAC

GO TO 1

C

C TRAPEZOIDAL RULE IF M IS EVEN

C

3

FAC=1./FAC

S(1)=FAC/2.

S(M)=FAC/2.

IF (MM.LT.2) RETURN

DO 4 I=2,MM

4

S(I)=FAC

RETURN

END

3

END OF SUBROUTINE GENS

BEGIN SUBROUTINE INIT

SUBROUTINE INIT (XINP,YINP,MINP,XC,YC,YY,ZZ,DMIN)

This subroutine selects starting values for the variables XC/YC  
If Xc -as input- is equal to zero. In addition, three vectors  
are generated which are needed in subroutine DETFS.

XINP,YINP Coord of the embankment X-section

MINP No. of Coord points XINP/YINP

Xc,YC Coord of the center of the arc

DMIN Minimum increment for the variables XC,YC and R

YY Minimum value for YC

ZZ Distance below max YINP down to which YC is permissible

H Thickness of the compressible layer

RHO(I) Slope of the line connecting XINP(I)/YINP(I) and  
XINP(I+1)/YINP(I+1)

TAU TAU=1.+RHO\*\*2

PSI(I) YINP-value of the above line for XINP=0

DIMENSION XINP(1),YINP(1)

COMMON/ SAPOD/ IDUTP,W,H,GLOAD,CLOAD,NARC,NRAD

```

COMMON/ INDET/ RHO(19),TAU(19),PSI(19)
C
  XX=XINP(MINP)-DMIN
  YY=YINP(1)
  DO 1 I=2,MINP
    J=I-1
    RHO(J)=(YINP(I)-YINP(J))/(XINP(I)-XINP(J))
    TAU(J)=1.+RHO(J)*RHO(J)
    PSI(J)=YINP(J)-RHO(J)*XINP(J)
    IF (YINP(J).GT.YY) YY=YINP(I)
1  CONTINUE
  YY=YY-ZZ
  IF (XC.NE.O.) GO TO 2
  YC=YY
  R=YY+H
  A=YY-YINP(1)
  RR=R*R
  XC=(XX+SQRT(RR-YY*YY)+SQRT(RR-A*A))/2.
2  RETURN
  END
C
C END OF SUBROUTINE INIT
C
C
C
C
C BEGIN SUBROUTINE LAGR
C
  SUBROUTINE LAGR (X,Y,M,JST,XX,YY,N)
C
C This subroutine interpolates the values of the function Y(X)
C from the knpwn YY(XX) by use of Lagrangian polynomial
C
C X Vector of arguements for which the values of the function are
C interpolated
C Y Vector of interpolated values starting with Y(JST)
C M No. of X-s
C XX Vector of arguements for which the values of the function
C are known
C YY Vector of known valuea of the function
C N No. of xx-s
C RN Auxiliary vector
C
  DIMENSION X(1),Y(1),XX(1),YY(1),RN(101)
C
  JS=JST-1
  DO 1 J=1,M
    JJ=JS+J
1  Y(JJ)=0.
C
  DO 3 K=1,N
    DO 4 J=1,M
4  RN(J)=1.
  RD=1.
C
  DO 2 I=1,N
    IF (I.EQ.K) GO TO 2
    DO 5 J=1,M
5  RN(J)=RN(J)*(X(J)-XX(I))

```

```

RD=RD*(XX(K)-XX(I))
CONTINUE
RD=YY(K)/RD
DO 6 J=1,M
JJ=JS+J
6 Y(JJ)=Y(JJ)+RN(J)*RD
3 CONTINUE

RETURN
END

```

END OF LAGR

BEGIN SUBROUTINE MATR

SUBROUTINE MATR (IS, IE, M, XV, A, XM)

Given the vector XV with elements  $XV(IS), XV(IS+1), \dots, XV(IE)$ , this subroutine generates the  $M$  by  $IE-IS+1$  matrix  $XM$ , whose elements are stored one dimensionally as follows--

$XM(1)=1.$ ,  $XM(2)=(XV(IS)-A)$ ,  $XM(3)=(XV(IS)-A)**2, \dots, XM(M)=(XV(IS)-A)**(M-1)$ ,  $XM(M+1)=1.$ ,  $XM(M+2)=(XV(IS+1)-A), \dots$ ,  $XM(M*(IE-IS+1))=(XV(IE)-A)**(M-1)$

Subtraction of  $A$  is done to increase the accuracy.

DIMENSION XV(1), XM(1)

```

K=0
DO 1 I=IS, IE
K=K+1
XM(K)=1.
XVT=XV(I)-A

```

IF STATEMENT TO INCLUDE CASE  $M=1$

```

IF (M.EQ.1) GO TO 1
DO 2 J=2,M
L=K
K=K+1
2 XM(K)=XM(L)*XVT
1 CONTINUE
RETURN
END

```

END OF MATR

begin subroutine minv

SUBROUTINE MINV (A, N, D)

This subroutine inverts a general matrix  $A$  by means of the standard Gauss-Jordan method.

DIMENSION A(1), L(1600), M(1600)

```
C
C SEARCH THE LARGEST ELEMENT
C
      D=1.0
      NK=-N
      DO 80 K=1,N
      NK=NK+N
      L(K)=K
      M(K)=K
      KK=NK+K
      BIGA=A(KK)
      DO 20 J=K,N
      IZ=N*(J-1)
      DO 20 I=K,N
      IJ=IZ+I
10      IF (ABS(BIGA)-ABS(A(IJ))) 15,20,20
15      BIGA=A(IJ)
      L(K)=I
      M(K)=J
20      CONTINUE
C
C INTERCHANGE ROWS
C
      J=L(K)
      IF (J-K) 35,35,25
25      KI=K-N
      DO 30 I=1,N
      KI=KI+N
      HOLD=-A(KI)
      JI=KI-K+J
      A(KI)=A(JI)
30      A(JI)=HOLD
C
C INTERCHANGE COLUMNS
C
35      I=M(K)
      IF (I-K) 45,45,38
38      JP=N*(I-1)
      DO 40 J=1,N
      JK=NK+J
      JI=JP+J
      HOLD=-A(JK)
      A(JK)=A(JI)
40      A(JI)=HOLD
C
C Divide column by minus pivot (value of pivot element is
C contained in BIGA)
C
45      IF (BIGA) 48,46,48
46      D=0.0
      RETURN
C PAGE P-80
C
48      DO 55 I=1,N
      IF (I-K) 50,55,50
50      IK=NK+I
      A(IK)=A(IK)/(-BIGA)
55      CONTINUE
C
C REDUCE MATRIX
```

```

DO 65 I=1,N
IK=NK+I
IJ=I-N
DO 65 J=1,N
IJ=IJ+N
IF (I-K) 60,65,60
60 IF (J-K) 62,65,62
62 KJ=IJ-I+K
A(IJ)=A(IK)*A(KJ)+A(IJ)
65 CONTINUE

```

DIVIDE ROW BY PIVOT

```

KJ=K-N
DO 75 J=1,N
KJ=KJ+N
IF (J-K) 70,75,70
70 A(KJ)=A(KJ)/BIGA
75 CONTINUE

```

PRODUCT OF PIVOTS

D=D\*BIGA

REPLACE PIVOT BY RECIPROCAL

```

A(KK)=1.0/BIGA
80 CONTINUE

```

FINAL ROW AND COLUMN INTERCHANGE

```

K=N
100 K=K-1
IF (K) 150,150,105
105 I=L(K)
IF (I-K) 120,120,108
108 JG=N*(K-1)
JR=N*(I-1)
DO 110 J=1,N
JK=JG+J
HOLD=A(JK)
JI=JR+J
A(JK)=-A(JI)
110 A(JI)=HOLD
120 J=M(K)
IF (J-K) 100,100,125
125 KI=K-N
DO 130 I=1,N
KI=KI+N
HOLD=A(KI)
JI=KI-K+J
A(KI)=-A(JI)
130 A(JI)=HOLD
GO TO 100
150 RETURN
END

```

END OF SUBROUTINE MINV

```

C
C BEGIN SUBROUTINE MODAL
C
C     SUBROUTINE MODAL (LAYER, IBC, N, FIMP, RC, RK, XD, XE, EIG, X, XI, F)
C
C This subroutine generates the coeff. matrix P, determines the
C characteristic equation which is then solved to give the eigen
C values EIG. knowing the eigenvalues, the modal matrix X is
C computed to generate its inverse XI. Generation of P depends
C on the boundary conditions which are indicated by LAYER, IBC
C CHI, RC, RK, XD and XE
C
C LAYER      Index for identification of drainage condition and
C            layer interface if any.
C LAYER=1    Horl Drainage
C LAYER=2    Vert. drainage, homogeneous soil
C LAYER.GE. 4 -Vert. drainage, two layers where layer gives
C            the location of the interface.
C IBC        Index for identification of boundary conditions
C IBC=1      Vert. drainage- Impeded drainage at bottom
C IBC=2      Vert. drainage- Free drainage at bottom
C IBC=3      Vert. drainage- No drainage at bottom
C FIMP       Impeded drainage factor
C RC         Ratio of coeff. of consol. (Lower/upper layer)
C RK         Ratio of coeff. of permeability (lower/upper layer)
C XD         Lower boundary of the solution domain. XD=0. if LAYER.GT. 1
C XE         Upper boundary of the solution domain. XE=H if LAYER.GT. 1
C EIG        Vector of eigenvalues
C X          Modal matrix=Matrix of eigenvectors
C XI         Inverse of X
C D, F       Auxiliary matrices
C P          Coeff. matrix
C N          No. of eigenvalues=No. of Nodal points in the program
C            numbering system.
C
C     DIMENSION P(100), D(50), F(1), EIG(1), X(1), XI(1)
C
C
C     IF (IBC.EQ. 4) GO TO 25
C     IF (LAYER.NE. 2) GO TO 1
C     IF (IBC.NE. 2) GO TO 2
C
C COMPUTE EIGEN VALUES AND MODAL MATRIX DIRECTLY FOR LAYER=2
C AND IBC=2
C
C     AN=N+1
C     AN=3.141592653589793/AN
C     KJ=0
C     DO 3 J=1, N
C     AJ=J
C     EIG(J)=-2. +2. *COS(AJ*AN)
C
C     DO 3 K=1, N
C     KJ=KJ+1
C     AK=K
C     X(KJ)=SIN(AK*AJ*AN)
C
C     CONTINUE
C     GO TO 4
C
C
C

```

```
2      IF (IBC.NE.3) GO TO 1
3      COMPUTE EIGEN VALUES AND MODAL MATRIX DIRECTLY FOR LAYER=2
4      AND IBC=3
```

```
      AN=2*N
      AN=3.141592653589793/AN
      KJ=0
```

```
      DO 5 J=1,N
      AJ=2*J-1
      EIG(J)=-2.+2.*COS(AJ*AN)
```

```
      DO 5 K=1,N
      KJ=KJ+1
      AK=K
      X(KJ)=SIN(AK*AJ*AN)
5      CONTINUE
      GO TO 4
```

```
1      GENERATE MATRICES P AND D FOR CASES WHERE 2.NE.IBC.NE.3
```

```
1      D(1)=1.0
      P(1)=0.0
      P(2)=2.0
      IF (IBC.LT.4) GO TO 6
```

```
1      CASE OF HORIZONTAL FLOW
```

```
25     AN=2*N
      AN=3.141592653589793/AN
      KJ=0

      DO 7 J=1,N
      AJ=2*J-1
      EIG(J)=-2.+2.*COS(AJ*AN)

      DO 7 K=1,N
      KJ=KJ+1
      AK=K
      X(KJ)=SIN(AK*AJ*AN)
7      CONTINUE
      GO TO 4
```

```
1      GENERATE P AND D FOR VERTICAL DRAINAGE
```

```
6      INT=N
      IF (LAYER.GT.2) INT=LAYER-2
      IF (LAYER.EQ.3) I=1
      GO TO 27
```

```
      DO 9 I=2,INT
      IE=2*I
      P(IE-1)=-1.
      P(IE)=2.
      D(I)=1.
9      CONTINUE
```

```
IF (INT.NE.N) GO TO 10
P(IE)=2.-FIMP
GO TO 8
```

```
C
C
C COEFFICIENTS OF P AND D FOR THE LAYERED CASE
C
```

```
10      PO=-RC*RC
        PE=2.*RC
        FIN=PE/(RC+RK)
        P(IE+1)=-FIN
        P(IE+2)=FIN*(1.+RK)
        D(INT+1)=FIN
        P(IE+3)=-FIN*RC*RK
        P(IE+4)=PE
        D(INT+2)=FIN*RC
        INT=INT+3
```

```
C
        DO 11 I=INT,N
        IE=2*I
        P(IE-1)=PO
        P(IE)=PE
        D(I)=RC*D(I-1)
11      CONTINUE
```

```
C
        IF (IBCV.NE.3) GO TO 12
        P(IE-1)=2.*PO
        D(N)=2.*D(N)
        GO TO 8
```

```
C
12      IF (IBCV.EQ.1) P(IE)=RC*(2.-FIMP)
```

```
C
C Call GENER to generate the characteristic equation and to compute
C the eigen values EIG
```

```
C
8       CALL GENER (P,F,EIG,N)
```

```
C
C Compute eigenvectors from P,D and EIG
```

```
C
        MEND=N-1
        NN=2*N
        DO 15 K=1,N
        NK=N*K
        X(NK)=1.
        X(NK-1)=P(NN)+EIG(K)
15      CONTINUE
```

```
C
        DO 16 ME=2,MEND
        NN=NN-2
        DO 16 K=1,N
        NK=N*K-ME
        X(NK)=P(NN+1)*X(NK+2)+(P(NN)+EIG(K))*X(NK+1)
16      CONTINUE
```

```
C
C Premultiply matrix X by matrix D
C Restore the X-elements since MINV destroys the original matrix
C
        I=0
        DO 20 J=1,N
        DO 20 K=1,N
```



```

      I=I+1
20    X(I)=X(I)*D(K)
      NN=N*N
      DO 17 I=1,NN
      XI(I)=X(I)
17    CONTINUE

```

```

C CALL MINV FOR INVERSION

```

```

      CALL MINV (XI,N,DET)

```

```

      RETURN
      END

```

```

C END OF SUBROUTINE MODAL

```

```

C SUBROUTINE MPRD BEGINS

```

```

      SUBROUTINE MPRD (A,B,R,N,M,L,IAS,IBS,IRS)

```

```

C This subroutine premultiplies the M*L matrix B by the N*M
C matrix A and stores the result in the N*L matrix R. The first
C elements of the matrices are A(IAS),B(IBS),R(IRS). The normal
C case will be that where IAS=IBS=IRS=1. If all matrices are
C stored one dimensionally, the following formula for the element
C R(IR) is obtained--- R(IR)=R(J+(K-1)*N+IRS-1)=SUM(I=1,M) of
C A(J+(I-1)*N+IAS-1)*B(I+(K-1)*M+IBS-1)

```

```

      DIMENSION A(1),B(1),R(1)

```

```

      IR=IRS-1
      KM=IBS-M-1
      DO 1 K=1,L
      KM=KM+M
      DO 1 J=1,N
      IR=IR+1
      IA=J+IAS-N-1
      IB=KM
      R(IR)=0.
      DO 1 I=1,M
      IA=IA+N
      IB=IB+1
      R(IR)=R(IR)+A(IA)*B(IB)
1     CONTINUE
      RETURN
      END

```

```

C END OF MPRD

```

```

C BEGIN RROOT

```

```

      SUBROUTINE RROOT (COF,XR,M)

```

```

C This subroutine computes the real roots of an M-th degree
C polynomial. COF is the coeff. vector with M+1 elements.
C XR is the vector containing the M roots. M must be
C greater than 2 but less than 90 because of storage
C allocation. The polynomial has the form F(X)=0. =
C COF(1)+COF(2)*X+.....+COF(M+1)*X**M
C A,B,C are auxiliary vectors of length M+1

```

```
C EPS gives the required accuracy.
C
      DIMENSION CDF(1),XR(1),A(50),B(50),C(50)
C
      EPS=1./1000.
      N=M
      NN=M+1
      X=0.
C
C Rename original coeff. for final iteration.
C
      DO 1 J=1,NN
      A(J)=CDF(J)
1      CONTINUE
C
C Apply newtons rule  $X(J+1)=X(J)-FX(X(J))/((D?DX)(F(XJ)))$ 
C and obtain the values of the function and its derivative
C for the guess X(J) from HORners scheme. The roots are
C always approximated from above and the last root is used
C as initial guess for the reduced polynomial.
C
2      B(NN)=A(NN)
      C(NN)=A(NN)
4      I=NN
C
      DO 3 J=2,N
      I=I-1
      B(I)=A(I)+X*B(I+1)
      C(I)=B(I)+X*C(I+1)
3      CONTINUE
      B(1)=A(1)+X*B(2)
C
C Newtons rule and accuracy check
C
      DX=-B(1)/C(2)
      X=X+DX
      EPAB=EPS*ABS(X)
      IF (ABS(DX).GT.EPAB) GO TO 4
      XR(N)=X
C
C Define coeff. of the reduced polynomial.
C
      DO 6 J=1,N
      A(J)=B(J+1)
6      CONTINUE
      NN=N
      N=N-1
      IF (N.GT.1) GO TO 2
      XR(1)=-A(1)/A(2)
C
C The roots are now stored as XR(1).LT.XR(2).LT. .... LT.XR(M)
C Make the final iteration using the original polynomial
C
      MM=M-1
      DO 7 K=1,MM
9      I=M+1
      DO 8 J=2,M
      I=I-1
      B(I)=CDF(I)+XR(K)*B(I+1)
      C(I)=B(I)+XR(K)*C(I+1)
```

8 CONTINUE

B(1)=COF(1)+XR(K)\*B(2)

DX=-B(1)/C(2)

XR(K)=XR(K)+DX

EPABK=EPS\*ABS(XR(K))

IF (ABS(DX).GT.EPABK) GO TO 9

7 CONTINUE

RETURN

END

END OF ROOT

SUBROUTINE STAB

SUBROUTINE STAB (XC, YC, R, XINP, YINP, MINP, MX, MYE, SU, FX, D, DM, YY)

This subroutine searches automatically for the smallest factor of safety starting with the initial data set XC, YC, R

The parameters have the following significance

Xc, YC Coord of the center of the arc

R Radius of the arc

XINP Coord of the points describing the x-section of the embankment

YINP No. of XINP/YINP points

MX No. of equally spaced points in X-dirn

MYE No. of equally spaced points in Y-dirn

SU Vector of shear strengths with MX\*MYE elements

FX Minimum factor of safety

D Maximum step size be used in the search program

DM Minimum step size be used in the search program

YY Minimum permissible value for YC

X, Y, Z Auxiliary vectors

DIMENSION XINP(1), YINP(1), SU(1), X(2), Y(2), Z(2)

Evaluate safety factor at initial base point

X(1)=YC

X(2)=XC

KEN=-1

11 KEN=KEN+1

DEL=D

CALL VARYR (X(1), X(2), R, XINP, YINP, MINP, MX, MYE, SU, FX, DM, YY)

4 FS=FX

DO 1 I=1, 2

Y(I)=X(I)

1 Z(I)=X(I)

EXPLORATORY MOVES

DO 2 I=1, 2

Y(I)=Z(I)+DEL

CALL VARYR (Y(1), Y(2), R, XINP, YINP, MINP, MX, MYE, SU, FY, DM, YY)

IF (FY.LT.FS) GO TO 5

```

Y(I)=Z(I)-DEL
CALL VARYR (Y(1),Y(2),R,XINP,YINP,MINP,MX,MYE,SU,FY,DM,YY)
IF (FY.LT.FS) GO TO 5
Y(I)=Z(I)
GO TO 2
5   FS=FY
2   CONTINUE
    IF (FS.LT.FX) GO TO 6
    IF (DEL.LE.DM) GO TO 10
    DEL=DEL/2.
    GO TO 4

C
C PATTERN MOVE
C
6   DO 3 I=1,2
    A=Y(I)-X(I)
    IF (A) 7,8,9
7   A=-2.*DEL
    GO TO 8
9   A=2.*DEL
8   B=X(I)
    X(I)=Y(I)
    Y(I)=B+A
3   CONTINUE
    FX=FS
    CALL VARYR (Y(1),Y(2),R,XINP,YINP,MINP,MX,MYE,SU,FS,DM,YY)
    IF (FS.LT.FX) GO TO 6
    GO TO 4

C
C Start new search if the circle giving the minimum safety factor
C so far does not outcrop at or in front of the embankment toe
C
10  IF (KEN.EQ.1) GO TO 12
    FMIN=FX
13  YC=X(1)
    XC=X(2)
    IF (KEN.EQ.1) GO TO 14
    IF ((XC+SQRT(R*R-YC*YC)).LT.XINP(MINP)) GO TO 11
    GO TO 14
12  IF (FMIN.GT.FX) GO TO 13
    FX=FMIN
14  RETURN

C
    END

C
C END OF STAB
C
C
C
C
    SUBROUTINE VARYR (YC,XC,R,XINP,YINP,MINP,MX,MYE,SU,FS,DMIN,YY)
C
C This subroutine evaluates the factors of safety for NRAD
C trial arcs with the same center XC/YC, but different radii.
C
    DIMENSION XINP(1),YINP(1),SU(1),F(10)
    DIMENSION C(6)
C
    COMMON/ SAPOD/ IDOUTP,W,H,QLOAD,CLOAD,NARC,NRAD
C
C Arcs whose centers lie below YY are not considered

```

IF (YC.LT.YY) go to 10

Determine minimum and maximum radii possible

```

RMIN=YC
IF (XC.LT.XINP(MINP)) GO TO 1
AI=XC-XINP(MINP)+DMIN
RMIN=SQRT(AI*AI+YC*YC)
1  RMAX=YC+H
   AI=YC-YINP(1)
   AI=SQRT(AI*AI+XC*XC)
   IF (RMAX.GT.AI) RMAX=AI
   IF (RMAX.GE.RMIN) GO TO 2
10  R=0.
   FS=.1E36
   FS=1.0E35
   GO TO 3
2  R=RMAX

```

Determine the factor of safety for the maximum radius

```

CALL DETFS (XC,YC,R,XINP,YINP,MINP,MX,MYE,SU,FS)
IF (RMAX.LE.(1.02*RMIN)) GO TO 3
NN=NRAD-1
IF (NN.EQ.0) GO TO 3
AI=NN
DELTA=(RMAX-RMIN)/AI

```

Determine the factors of safety for arcs with radii  
 $RR=RMIN+(I-1)*DELTA$ , and store them in vector F at place  $2*I-1$

```

RR=1.00001*RMIN-DELTA
DO 4 J=1,NN
RR=RR+DELTA
CALL DETFS (XC,YC,RR,XINP,YINP,MINP,MX,MYE,SU,F(J))
4  CONTINUE

```

Search for the minimum factor of safety which is then  
returned to the calling program together with the  
corresponding radius

```

DO 5 I=1,NN
IF (F(I).GE.FS) GO TO 5
FS=F(I)
AI=I-1
R=RMIN+AI*DELTA
5  CONTINUE
3  RETURN
   END

```

END OF VARYR

BEGIN SUBROUTINE EFGEN

SUBROUTINE EFGEN (PSI,T,EIG,IVAR,MM,NN,D,LI)

This subroutine generates the time-dependent diagonal matrix D

```
C PSI      Vector which considers the influence of the soil parameters
C T        Time for which the diagonal matrix D is generated
C EIG      Vector of eigen values
C IVAR=0   Const. soil parameters
C IVAR=1   Variable soil parameters
C MM=      No. of points XT for which D must be evaluated
C NN       No. of eigenvalues
C D        Diagonal matrix to be returned
```

```
C
      DIMENSION PSI(1),EIG(1),D(1)
```

```
C
      EF=64.
```

```
      IF (T.NE.0.) GO TO 7
```

```
      LAST=MM*NN
```

```
      DO 8 I=1,LAST
```

```
      D(I)=1.0
```

```
      RETURN
```

```
7      IF (IVAR.EQ.0) GO TO 1
```

```
C
C VARIABLE SOIL PARAMETERS
```

```
      II=0
```

```
      DO 2 J=1,MM
```

```
      PSIT=PSI(J)*T
```

```
      DO 2 I=1,NN
```

```
      if (MM.EQ.1) PSIT=PSI(I)*T
```

```
      II=II+1
```

```
      D(II)=10.**((PSIT*EIG(I)/2.302585)/EF)
```

```
2      CONTINUE
```

```
      RETURN
```

```
C
C CONSTANT SOIL PARAMETERS
```

```
1      PSIT=PSI(1)*T
```

```
      do 3 I=1,NN
```

```
      D(I)=10.**((PSIT*EIG(I)/2.302585)/EF)
```

```
      IF (MM.LT.2) GOTO 3
```

```
      II=I
```

```
      DO 6 J=2,MM
```

```
      II=II+NN
```

```
6      D(II)=D(I)
```

```
3      CONTINUE
```

```
      RETURN
```

```
C
      END
```

```
C
C END OF SUBROUTINE EFGEN
```



COVER DESIGN BY ALDO GIORGINI